557
W27b
no.54

Geol.

State of Washington
DANIEL J. EVANS, Governor

THE LIBRARY OF THE
FEB 17 1967
UNIVERSITY OF ILLINOIS

Department of Conservation
H. MAURICE AHLQUIST, Director

---

DIVISION OF MINES AND GEOLOGY
MARSHALL T. HUNTTING, Supervisor

Bulletin No. 54

# Geology and Mineral Resources of the KELSO-CATHLAMET AREA, Cowlitz and Wahkiakum Counties, Washington

By
VAUGHN E. LIVINGSTON, JR.

FEB 22 1967

1889

THE LIBRARY OF THE
FEB 8 1967
UNIVERSITY OF ILLINOIS

STATE PRINTING PLANT, OLYMPIA, WASH.
1966

GEOLOGY LIBRARY

The person charging this material is responsible for its return on or before the **Latest Date** stamped below.

**Theft, mutilation, and underlining of books are reasons for disciplinary action and may result in dismissal from the University.**

University of Illinois Library

APR 19 1968

L161—O-1096

State of Washington
DANIEL J. EVANS, Governor

Department of Conservation
H. MAURICE AHLQUIST, Director

---

DIVISION OF MINES AND GEOLOGY
MARSHALL T. HUNTTING, Supervisor

Bulletin No. 54

# Geology and Mineral Resources of the KELSO-CATHLAMET AREA, Cowlitz and Wahkiakum Counties, Washington

By
VAUGHN E. LIVINGSTON, JR.

1889

STATE PRINTING PLANT, OLYMPIA, WASH.
1966

**For sale by Department of Conservation, Olympia, Washington.**
**Price, $1.50.**

# FOREWORD

Although approximately one-third of the installed aluminum smelting capacity in the United States is located in the Northwest, none of the ore to supply these plants is mined in the area. The large local potential market for bauxite has encouraged exploration in Washington and Oregon since the early 1940's.

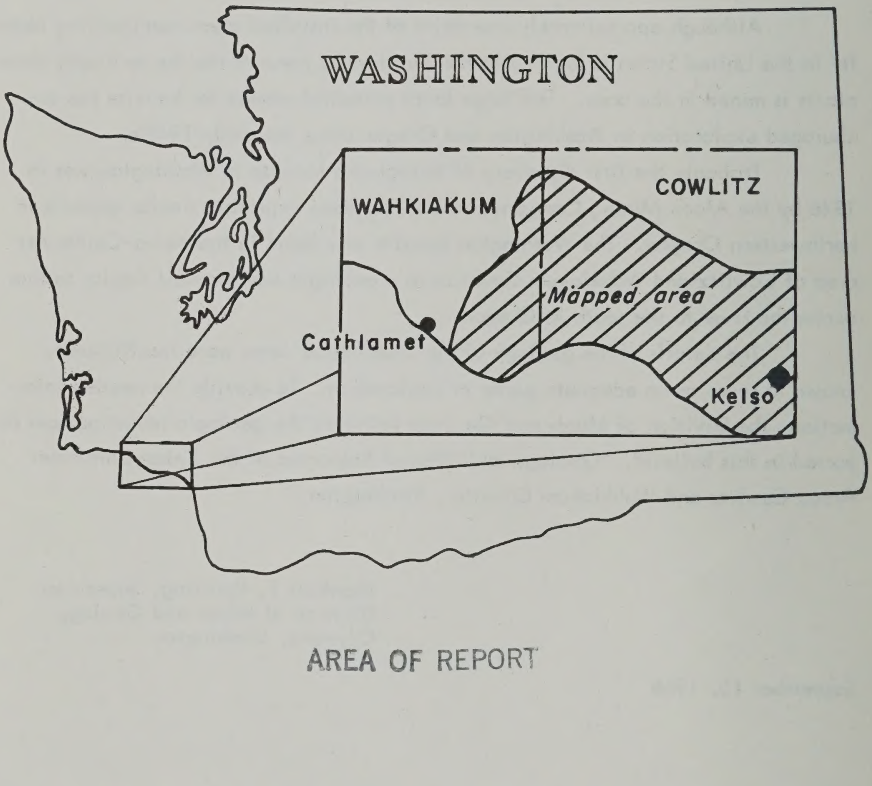
Probably the first discovery of ferruginous bauxite in Washington was in 1946 by the Alcoa Mining Company, which had been exploring similar deposits in northwestern Oregon. The Washington bauxite was found in the Kelso-Cathlamet area of Cowlitz and Wahkiakum Counties in a geologic environment similar to that across the river to the south in Oregon.

The details of the geology of the Washington area were insufficiently known to serve as an adequate guide to exploration. To provide the needed information, the Division of Mines and Geology initiated the geologic investigations reported in this bulletin, "Geology and Mineral Resources of the Kelso-Cathlamet Area, Cowlitz and Wahkiakum Counties, Washington."

Marshall T. Huntting, Supervisor
Division of Mines and Geology
Olympia, Washington

September 15, 1966

8767dig


WASHINGTON
WAHKIAKUM
COWLITZ
Mapped area
Cathlamet
Kelso

AREA OF REPORT

# CONTENTS

Page

Foreword ........ 3

Abstract ........ 11

Introduction ........ 12

- Purpose and location ........ 12
- Previous work ........ 13
- Culture ........ 13
- Climate and vegetation ........ 14
- Topography ........ 15
- Drainage and water supply ........ 15
- Field work and acknowledgments ........ 16

General geology ........ 17

- Stratigraphy ........ 19
  - Older Eocene volcanic rocks ........ 19
  - Cowlitz Formation ........ 19
    - Age and correlation ........ 24
    - Contact relations ........ 31
  - Goble Volcanics ........ 31
    - Age and correlation ........ 33
    - Contact relations ........ 36
  - Oligocene sedimentary rocks ........ 36
    - Contact relations ........ 37
  - Columbia River Basalt ........ 37
    - Age and correlation ........ 41
    - Contact relations ........ 41
  - Troutdale Formation ........ 41
    - Age and correlation ........ 44
    - Contact relations ........ 45
  - Post-Troutdale silty clay ........ 45
    - Age and correlation ........ 46
    - Contact relations ........ 46
  - Terrace deposits ........ 46
    - Age and correlation ........ 47

## CONTENTS

Page

General geology—Continued

Stratigraphy—Continued

Landslides .......... 47
Alluvium .......... 48
Intrusive rocks .......... 49
Plugs .......... 49
Ordway Creek intrusive .......... 49
Dikes .......... 51
Structure .......... 52
Folds .......... 52
Willapa Hills anticline .......... 52
Bradley Heights syncline .......... 52
Columbia Heights anticline .......... 53
Hazel Dell syncline .......... 53
Minor folds .......... 53
Faults .......... 53
Kelso fault .......... 54
Harmony Creek faults .......... 54
Abernathy Creek fault .......... 54
Other faults .......... 55
Historical geology .......... 56
Economic geology .......... 58
Coal .......... 58
Anchor mine .......... 58
Coal Creek mine .......... 59
Oil and gas .......... 61
Sand, gravel, and crushed rock .......... 61
Peat .......... 62
Ferruginous bauxite .......... 62
Location and previous investigations .......... 62
Age of laterization .......... 63
Description of the deposits .......... 63
Mineralogy of the bauxite .......... 69
Origin of the bauxite .......... 72

Page

Economic geology—Continued

Ferruginous bauxite—Continued

Analyses of samples ........ 76

Economics of the bauxite ........ 89

Appendix A—Analytical procedures ........ 97

Northwest Testing Laboratories, Portland, Oregon ........ 97

Metallurgical Laboratory, Seattle, Washington ........ 97

Phosphate method for aluminum as outlined by Keefer, of Anaconda ........ 97

Caustic soda precipitation method ........ 98

Cupferron method ........ 98

Appendix B—Description of cores ........ 100

Selected references ........ 105

## ILLUSTRATIONS

Page

Figure 1. Index map showing location of the Kelso-Cathlamet area ...... 12

2. Photomicrograph showing typical clot of plagioclase phenocrysts in volcanic flows of the Cowlitz Formation ........... 22

3. Photomicrograph showing aligned plagioclase crystals in a volcanic flow of the Cowlitz Formation .................... 23

4. Photomicrograph of Columbia River Basalt .................... 38

5. Interflow conglomerate in Columbia River Basalt ............. 40

6. Troutdale conglomerate exposed in a gravel pit .............. 43

7. Photomicrograph showing the granophyric texture of the Ordway Creek intrusive ................................ 50

8. Coal section at the west portal of the Anchor mine ........... 59

9. Coal section at the Coal Creek mine ....................... 59

10. Stella Heights upland surfaces on which bauxite occurs ........ 64

11. Typical bauxite nodule that has weathered out of the ore zone . 66

12. Photomicrograph of bauxite nodule, using plane light, showing relict igneous texture ................................... 67

13. Photomicrograph of same bauxite nodule, using crossed nicols .. 67

14. Photomicrograph of pisolitic bauxite ........................ 68

15. Differential thermal analysis curves on samples from Core Hole No. 4 ............................................ 70

16. Diagram showing variation in chemical composition of bauxite with depth ........................................... 74

17. Diagrammatic section from the surface through the bauxite horizon ............................................... 75

18. Flowsheet of the Pedersen method of producing alumina and pig iron from ferruginous bauxite .......................... 90

19. Flowsheet of double-leach process of Holbrook and Yerkes ..... 92

20. Flowsheet of Commonwealth Scientific and Industrial Research Organization process for alumina extraction ........ 93

21. Spatial relations of the ferruginous bauxite deposits of Washington and Oregon ................................ 96

22. Geologic map and cross section of the Kelso area ....... In pocket

23. Preliminary geologic map and cross section of the Cathlamet-Coal Creek area ......................... In pocket

## TABLES

Page

Table 1. Stratigraphic sequence in the Kelso-Cathlamet area ........ 18

2. Analysis of Columbia River Basalt from Alder Bluff .......... 39

3. Screen analysis of Troutdale sand ........................ 42

4. Two partial sections of the Troutdale Formation ............ 44

5. Sieve and pipette analysis of terrace silt .................. 47

6. Log of Reynolds Metals Company water well ............... 48

7. Chemical analysis of the Ordway Creek intrusive ........... 51

8. Analyses of coal from the Coal Creek mine (from Diller, 1905, p. 412) ........................................... 60

9. Identified X-ray diffraction peaks ....................... 72

10. Check analyses of duplicate samples by six analysts ......... 77

11. Chemical analyses of samples that were highest in $Al_2O_3$ as indicated by differential thermal analyses ............ 78-87

12. Assay record of samples from a Reynolds Metals Company core hole ............................................ 88

13. Average of analyses of ferruginous bauxite from Cowlitz County, Washington and Columbia County, Oregon ....... 88

14. Average of analyses of laterite from Cowlitz County based on several thousand samples ........................... 89

15. Results of seven test runs using the Pedersen process to reduce ferruginous bauxite ............................ 91

# GEOLOGY AND MINERAL RESOURCES OF THE KELSO-CATHLAMET AREA, COWLITZ AND WAHKIAKUM COUNTIES, WASHINGTON

---

By Vaughn E. Livingston, Jr.

---

## ABSTRACT

The Kelso-Cathlament area is underlain by rocks as old as Eocene and as young as Recent. The Eocene rocks are made up of three formations — the oldest being the basalts that underlie the Cowlitz Formation and the youngest the Goble Volcanics that interfinger with and overlie the Cowlitz. Oligocene rocks include the top part of the Goble Volcanics and also the massive siltstones found in the western part of the area. The Miocene rocks are black lava flows of the Columbia River Basalt and intercalated sedimentary beds. Pliocene rocks are restricted to moderately consolidated conglomerates, and Pleistocene and Recent materials consist of unconsolidated sand, gravel, silt, and landslide debris.

Predominant structural trends are to the northwest; folds of less magnitude trend east-west. Dips are generally low, the average being near 20°, the highest about 50°. Faults are common and some have strike slip movement. Original deformation took place after the outflowing of Goble Volcanics stopped. A second period of uplift took place after the outflowing of Columbia River Basalt. Two periods of subsidence and uplift have subsequently taken place — one, during Pliocene to early Pleistocene, when the Troutdale Formation was deposited and then eroded; the second, during late Pleistocene, when the terraces along the Cowlitz River were deposited and then exposed.

Mineral deposits in the area consist of ferruginous bauxite, coal, stone, sand and gravel, and peat. The ferruginous bauxite appears to have the greatest potential for future development. These deposits were formed by laterization of the uppermost flows of the Columbia River Basalt. The bauxite averages about 38 percent $Al_2O_3$, 6 percent $SiO_2$, 27 percent $Fe_2O_3$, and 4 percent $TiO_2$ through the ore zone, which averages about 12 feet in thickness.

## INTRODUCTION

Purpose and location. — This report was prepared to describe the geology and mineral resources of the Kelso-Cathlamet area. Even though this is a region of Washington State that is generally thought of as not having much mineral wealth, there are deposits within the area that warrant attention and that in the future may provide Cowlitz and Wahkiakum Counties with substantial industries.

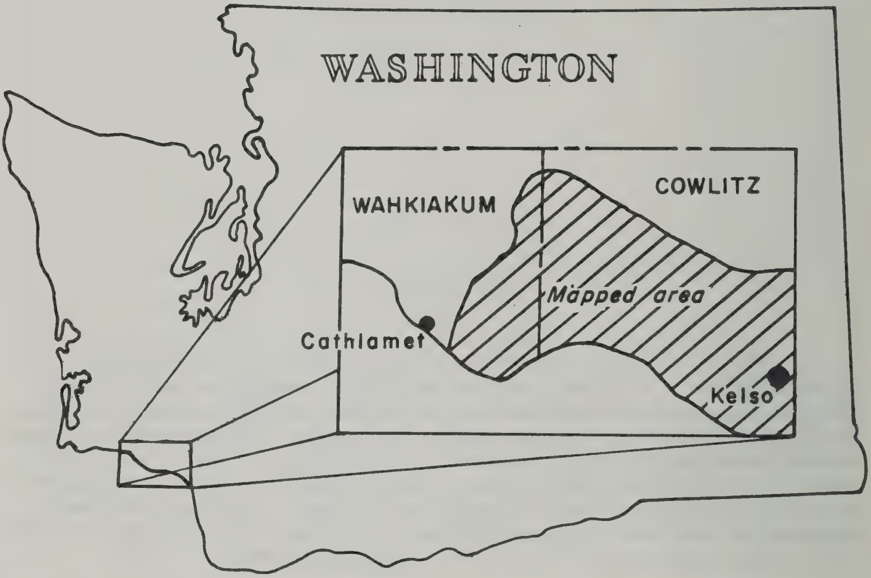


FIGURE 1.— Index map showing location of the Kelso-Cathlamet area.

The area described in this report is bounded approximately by the Cowlitz River on the east, the Elochoman River on the west, the Columbia River on the south, and about 46°20' north latitude on the north. The region is covered by the Kelso $7\frac{1}{2}$-minute quadrangle, the north halves of the Clatskanie and Cathlamet quadrangles, the south half of the Ryderwood quadrangle, and a little strip along the southeast part of the Skamokawa quadrangle.

The Kelso $7\frac{1}{2}$-minute quadrangle was mapped in detail, but the rest of the area was mapped in preliminary fashion in conjunction with outlining the area underlain by Columbia River Basalt. Consequently, the geology is shown on two maps (Figs. 22 and 23, in pocket).

Previous work.—Prior to 1959, when this project was begun, practically all published geologic reports on the Kelso-Cathlamet area were largely generalized. Only oil company geologists, whose work is not available to the public, had done detailed mapping. Published detailed work consisted of descriptions of certain coal mines and clay deposits, and a stratigraphic section measured along Coal Creek.

The earliest recorded work is that of James D. Dana (1849), who examined rocks along the Columbia River and its tributaries, including the Cowlitz River. This was done in connection with the exploration of the Oregon Territory under the leadership of Charles Wilkes. Joseph Diller (1905) examined and described the stratigraphy at the Coal Creek mine in sec. 26, T. 19 N., R. 3 W. Diller and others (1916) also compiled a series of simple reconnaissance maps that paralleled the Union Pacific Railway tracks from Seattle, Washington, to Los Angeles, California. One of these maps shows the geology along the Cowlitz River through the area covered by this report. Weaver (1916c) published a report on the faunal zones of western Washington, in which he described several fossils that occur along Coal Creek. In the same year, Weaver (1916a) described the stratigraphy and presented a broad structural interpretation of the geology of western Washington. Culver (1919) described the general geology and the coal mines of the Castle Rock-Kelso area. Weaver and Palmer (1922) described many species of Eocene fossils from Washington, several of which came from beds exposed along Coal Creek. A preliminary geologic map of the State was prepared by Culver (1936); this map gave the general Tertiary stratigraphy of southwest Washington but lacked detailed information. In 1937 Weaver (1937b) published a report on the Tertiary stratigraphy of western Washington and northwestern Oregon, in which were included a stratigraphic section of the Cowlitz Formation measured along Coal Creek and a map that covered a small part of the Coal Creek area. Glover (1941) described some clay deposits near Kelso. In a detailed paleontological study of the Tertiary fossils of the Northwest, Weaver (1943) included many that came from the area covered by this report. Huntting and others (1961) published a geologic map of Washington that showed considerable stratigraphic detail but lacked structural information.

Culture.—The principal cities of the area are Longview and Kelso, situated at the confluence of the Cowlitz River with the Columbia River in the southeast corner of the region, and Cathlamet, at the southwest corner of the area. The rest of the communities are small, usually consisting of a few houses clustered around a store. These are Ostrander, near the junction of Ostrander Creek and the Cowlitz River; Lexington, across the Cowlitz River to the west of Ostrander; Coal Creek, about 2 miles up Coal Creek from the Columbia River valley; Eufaula, about 1 mile up Harmon Creek (previously called Mosquito Creek, U.S. Board on Geographic Names, 1959, p. 43) from its junction with Coal Creek; Stella, at the junction of Germany Creek and the Columbia River; and Oak Point, about half a mile up Mill Creek from its confluence with the Columbia River.

The principal industries of the area are logging, the manufacture of wood products, and the production of aluminum ingot and extrusion products. Agriculture plays a minor role in the economy, and commercial fishing for salmon and smelt is seasonal.

The area is accessible by highway, railroad, airline, and by ocean-going ships. Highway U.S. 99 extends north-south through the area along the east side of the Cowlitz River. It is paralleled by double railroad tracks that are used jointly by the Union Pacific, Northern Pacific, and Great Northern railway companies. Highway U.S. 830 extends east-west through the area, following along the north bank of the Columbia River. County, city, and private roads are numerous and so located that in only a few places is it possible to get more than a mile away from a road of some kind. The City of Longview's port on the Columbia River has facilities to accommodate ocean-going cargo ships. The ship channel in the Columbia is maintained at 35 feet in depth and 500 feet in width. The area is within the Bonneville Power Administration's transmission area. Power needs that exceed 10,000 kw can be furnished through Bonneville, and lesser needs can be supplied by the Cowlitz County Public Utility District.

Climate and vegetation.—The Kelso-Cathlamet area has a moist temperate climate. The winter months are cool and wet; the summers are warm and dry. Average yearly rainfall is about 45 inches, and average yearly temperature is about 52°. Highest recorded temperature during the period between 1929 and 1958 was 105°, in July of 1942, and the lowest reading for the same period was -20°, in January of 1930. However, days when the temperature rises above 90° or falls below 20° are unusual.

The vegetation is typical of southwestern Washington. The economically important coniferous trees are Douglas fir (*Pseudotsuga taxifolia*), western hemlock (*Tsuga heterophylla*), and western red cedar (Thuja *plicata*). The Douglas fir and hemlock thrive on the well-drained valley and upland slopes, and the cedar grows in the poorly drained river and creek bottoms. Other, less common, evergreens are the Sitka spruce (Picea sitchensis), lodgepole pine (Pinus contorta), Grand fir (Abies grandis), and Pacific yew (Taxus brevifolia). Deciduous trees that occur in the area are willows (Silex sp.), big leaf maple (Acer macrophyllum), Pacific dogwood (Cornus nuttallii), Pacific madrone (Arbutus menziesii), northern black cottonwood (Populus trichocarpa), cascara (Rhamnus purshiana), and alder (Alnus rubra). The underbrush is mostly devilsclub (Ophopanax horridum), Oregon grape (Berberis equifolium), elderberry (Sambacus caerbe), salal (Gaultheria shallon), and blackberry (Rubus vitifalius).

Topography.—Elevations range from 4 feet above sea level in the Columbia River valley to about 2,500 feet along the ridge that forms the north border of the area. There are three distinct types of topography represented in the area. These, in increasing order of elevation, are: broad, flat-bottomed river valleys; gently rolling upland; and sharp-ridged highlands. The upland surface has developed on the flat-lying flows of the Columbia River Basalt. Steep-sided ridges in the intricately dissected highlands have been carved in the folded and faulted sedimentary and volcanic rocks of the Cowlitz Formation and the Goble Volcanics.

The Columbia River valley is about 4 miles wide at Longview, narrows to about 2 miles at Stella, then broadens out to between 3 and 4 miles downriver through the area. The most striking topographic feature of the valley is Mount Solo, a 2-mile-long, 600-foot-high ridge that stands isolated in the middle of the flood plain about 2 miles west of Longview. It is an erosional remnant left standing when the river changed its course from the north to the south side of the valley.

The valley of the Cowlitz River averages about 1½ miles in width through the area except at Rocky Point, where it is constricted to a width of approximately 1,500 feet. The valley is bordered by gentle slopes, and the flood plain is lined with low terraces, the highest of which stands about 180 feet above sea level.

Drainage and water supply.—The Columbia River and one of its principal tributaries, the Cowlitz River, are the main streams in the area. The Columbia flows northward into the area, then at Longview turns west toward the ocean. The average discharge at Longview is estimated to be in excess of 250,000 cfs. 1/

---

1/ There is no gaging station at Longview, so discharge totals from tributaries downstream from The Dalles, Oregon, were added to The Dalles station discharge to arrive at this figure.

The Cowlitz River springs from glaciers on the southeast side of Mount Rainier. Because of its glacial source and the fact that one of its largest tributaries receives glacial melt water from Mount St. Helens, the Cowlitz River is heavily laden with silt during the summer months. Its average discharge at Kelso is 8,772 cfs, and it drains approximately 2,500 square miles.

The Coweman River enters the area at the southeast corner, where it flows west and then south before it empties into the Cowlitz River. Its average discharge at Kelso is 380 cfs, and it drains an area of approximately 119 square miles.

Coal Creek drains the central part of the area. It flows southward into the valley of the Columbia, then turns west and parallels the Columbia to Stella, where the two streams join. Most of its water is from surface runoff, the remainder coming from ground water sources.

Delameter Creek drains the north part of the area. It flows southward into the area near the center of sec. 23, T. 9 N., R. 3 W., makes a wide, almost 180° turn, and flows north from the area near the E. $\frac{1}{4}$ cor. sec. 24, T. 9 N., R. 3 W. Delameter Creek receives its water from surface runoff and ground water sources.

A series of four south-flowing streams drain the area west of Coal Creek. Germany Creek enters the Columbia River at Stella; it drains 23 square miles and has an average yearly discharge of 30 cfs. Abernathy Creek enters the Columbia in sec. 10, T. 8 N., R. 4 W., on the east side of Abernathy Point. It drains 20 square miles and has an average yearly discharge of 108 cfs. Mill Creek joins the Columbia in sec. 9, T. 8 N., R. 4 W., on the west side of Abernathy Point; it drains 28 square miles and has an average yearly discharge of 116 cfs. The Elochoman River is the western boundary of the area. It enters the Columbia just west of Cathlamet, drains 66 square miles, and has an average yearly discharge of 359 cfs.

Field work and acknowledgments.—A total of 22 weeks of field work on this project was done during the summer seasons of 1959, 1960, 1961, and 1962. Mapping was done on U.S. Geological Survey topographic quadrangle maps with the aid of vertical aerial photographs.

The author wishes to express thanks to the land owners of the area for the courtesy they extended him in allowing access across their property. Floyd Morales, Cowlitz County Forester, loaned to the author aerial photographs of the area. Shell Oil Company loaned several foraminiferal slides from the area and donated some auger-hole samples from near Kelso that contained diagnostic foraminfera.

R. E. Corcoran, of the Oregon Department of Geology and Mineral Industries (formerly of Harvey Aluminum Company), and T. L. Neathery, of Reynolds Metals Company, contributed much valuable information through the discussions the author had with them concerning the origin and occurrence of the bauxite deposits. W. A. Call, of the U.S. Department of Agriculture Soil Conservation Service in Kelso, gave aid in identifying soils that were derived from the various formations. H. L. Heckmann, of Harvey Aluminum Company; B. G. McNish, of Aluminum Company of America; H. J. Olsen, of American Metal Climax, Inc.; and J. H. Moses, of Reynolds Metals Company, are thanked for the information on analyses that they generously gave. The writer is indebted to E. A. Magill and G. J. Carter, of the U.S. Bureau of Mines, for making differential thermal and X-ray analyses of ferruginous bauxite samples. P. D. Snavely, of the U.S. Geological Survey, is thanked for rock analyses that he supplied. Professor R. K. Sorem, of Washington State University, is thanked for the X-ray identification work he did on certain minerals from the area. D. R. Fenton, of the University of Washington Department of Oceanography, made X-ray spectrographic analyses of several samples, for which he is thanked. Thanks are also due the staff members of the Division of Mines and Geology for helpful criticism in preparing this manuscript. Special thanks are due Wayne S. Moen and W. A. G. Bennett for help in the petrographic work, G. W. Thorsen for surveying and sampling assistance in the field, and W. W. Rau for foraminiferal identifications.

## GENERAL GEOLOGY

The Kelso-Cathlamet area is underlain by rocks of Tertiary age. Interfingering Eocene and Oligocene sedimentary and volcanic rocks make up most of the eastern and northern parts of the region, and Miocene volcanic rocks that include a few sedimentary interbeds underlie the southern and western parts of the area. Table 1 shows the stratigraphic relationships of these units.

TABLE 1.—Stratigraphic sequence in the Kelso-Cathlamet area

| Age | Formation | Lithologic character | Map symbol | Thickness (feet) |
|---|---|---|---|---|
| Recent | Alluvium | Gravel, sand, and silt deposits along streams. Includes peat bogs in the Columbia valley west of Longview. | Al | 250+ |
| | | Unconformity. | | |
| Pleistocene | Landslide debris | Heterogeneous mixture of detached Tertiary bedrock and Quaternary deposits. | Ls | |
| | | Unconformity. | | |
| | Terrace deposits | Fine sand and silt along the Cowlitz and Coweman Rivers. | Qt | 160± |
| | | Unconformity. | | |
| Pliocene | Post-Troutdale silty clay | Massive light-brown clayey silt, upper part; and red to mottled red and gray heavy silty clay, lower part. In most places has a gibbsitic pisolitic zone at base. | | 40± |
| | | Unconformity. | | |
| | Troutdale Formation | Poorly consolidated conglomerate, gritstone, sandstone, and claystone. Scattered quartzite pebbles and cobbles are diagnostic of the formation. | Tt | 900 |
| | | Unconformity. | | |
| Miocene | Columbia River Basalt | Dense black aphanitic basalt, vesicular in part, columnar and blocky jointed, and containing occasional sandstone and conglomerate interbeds. Gives way to marine sediments to the west. | Tcr | 1,400± |
| | | Unconformity. | | |
| Oligocene | Oligocene sedimentary rocks | Massive dark- to light-gray siltstone. | To | ? |
| Eocene-Oligocene | Goble Volcanics | Basaltic flows, flow breccia, pyroclastic material, and intercalated sedimentary beds. | Tgr | 1,000± |
| Eocene | Cowlitz Formation | Massive to thin-bedded arkosic sandstone, siltstone, and shale, also some conglomerate, gritstone, and volcanic sandstone. Contains coal locally. Formation is coarser to the east. Basaltic unit, which is made up of flows, pyroclastic and sedimentary rocks, interfingers from south. | Tc<br>Tcv | 1,800+ |
| | Older Eocene volcanic rocks | Light-gray-weathering, soft, chloritized basalt flows. | Ev | ? |
| INTRUSIVE IGNEOUS ROCKS | | | | |
| Post-Cowlitz | Dikes and plugs | Basaltic dikes and glassy basaltic plugs. | Ti | |
| Tertiary | Hypabyssal intrusive | Monzonite to quartz monzonite plug. | Tig | |

## Stratigraphy

### Older Eocene Volcanic Rocks

The oldest rocks in the Kelso-Cathlamet area are light-gray-weathering, soft chloritized Eocene basalts that crop out in the core of the Willapa Hills anticline in the S$\frac{1}{2}$ sec. 7, T. 10 N., R. 4 W. A cursory examination indicates that they occur stratigraphically beneath the Cowlitz Formation, but the contact relations were not observed. They are probably correlative to the east with the Metchosin of Henriksen (1956, p. 22) and to the north with the Crescent(?) Formation of Pease and Hoover (1957).

### Cowlitz Formation

The name "Cowlitz Formation" was proposed by Weaver (1912, p. 13) for the gray siltstone beds that crop out along the Cowlitz River about 1$\frac{1}{4}$ miles east of Vader in Lewis County, Washington. Weaver (1916a) later described the stratigraphy, structure, and lithology of the Cowlitz Formation, although he did not call it specifically by name, from Castle Rock to Winlock. He estimated the formation to be about 8,000 feet thick (p. 91). In that same year (1916b) he indicated that 4,970 feet of Cowlitz sediments are exposed along Olequa Creek between Olequa and Winlock, and possibly 6,000 feet between Castle Rock and Olequa, for a possible thickness of 10,900 feet. He also implied (p. 6) that the lower part of the formation was exposed along Stillwater Creek southwest of Vader, but did not describe it. Henriksen (1956, p. 35) appended the Stillwater Creek section to the type section and found that the Cowlitz Formation rests conformably on volcanic rocks of middle Eocene age. He also divided the Cowlitz Formation into four members: the lower Stillwater Creek Member with the Pe Ell Volcanic Member interfingering from the west, and the upper Olequa Creek Member with the Goble Volcanic Member interfingering from the southeast.

The Cowlitz Formation in the Kelso-Cathlamet area consists of over 1,800 feet of intercalated sandstone, siltstone, mudstone, and shale beds, as well as basalt flows and pyroclastic rocks. The sandstone units, which are the most abundant, are laminated to massive bedded. The massive and thick-bedded units are commonly crossbedded and usually are more coarse grained than the thinner bedded units. Laminations are almost always the result of thin layers (1± mm) of carbonaceous material being intercalated with the sand. Bedding of the sandstone is commonly defined by thin claystone, shale, or siltstone partings.

Sand grain size varies between the upper and lower limits of sand size according to the Wentworth scale, but most beds are made up of fine to very fine (1/8 to 1/16 mm) grains. The grains are angular in the finer sizes, but are slightly subangular in some of the coarser grained material. The matrix or binder is mostly clay or clay-size material; however, some units are cemented by limy material. The lime-cemented units are much more resistant to erosion than those having a clay matrix, and it is common to find them forming cliffs and waterfall ledges along the stream courses. Practically all of the units with a clay binder are friable on weathered surfaces.

On fresh surfaces most of the sandstones are light to dark gray; a few beds are very light gray to almost tan. The arkosic sandstone outcrops weather tan to light gray and have bands and clots in varying tones of pink to dark-brown caused by iron staining. The basaltic sandstone units have a light-green to dark-green speckled appearance on fresh surfaces and weather to mottled dark brownish red and dark gray. Sorting, which varies from good to poor, is best in the arkosic units and poorest in the basaltic units.

In the samples examined petrographically, feldspar is the most abundant mineral constituent of the sandstone, followed by quartz, mica, and rock fragments, in decreasing order of abundance. In a few tuffaceous samples, volcanic glass shards, both clear and devitrified, are abundant. Heavy minerals (sp. gr. $> 2.83$) make up a very small proportion (considerably less than 1 percent) of the samples examined. Most abundant in the heavy mineral suite are biotite, amphibole, zircon, garnet, and nonmagnetic black opaque grains.

The shales and mudstones are commonly silty to sandy, and they vary in thickness from very thin partings in coarser grained sediments to units many feet thick. Shale beds are commonly finely micaceous and carbonaceous; the latter is especially true where they are associated with coal seams. The mudstones characteristically are thicker than the shale units and have very little carbonaceous material associated with them. On fresh surfaces the mudstones are generally lighter colored than the shales, but both vary from almost black to light gray. Many of the shale beds are carbonaceous to lignitic, especially in the Coal Creek area. Exposed surfaces weather to various hues of light gray and brown and have occasional bands and streaks of rust-red iron staining.

The siltstones are generally sandy and micaceous, but some are carbonaceous, tuffaceous, or shaly. Typically, they are medium gray on fresh surfaces and light gray to tan where exposed to weathering. Bedding varies from thin laminations to massive units several feet thick.

The Cowlitz Formation exhibits a mixed marine-nonmarine lithology along the Cowlitz River and Coal Creek. Foraminifera found in samples from Clark Creek and Delameter Valley indicate a fairly shallow water environment. Coarse clastics and a shallow marine and brackish water invertebrate fauna indicate a near-shore environment, and the coal beds imply deposition in low swampy areas. Farther to the northwest, along the headwaters of Germany Creek, coarse clastics and coal beds are missing from the section, and the proportion of claystone and shale to sandstone appears to be increased. This, coupled with the presence of Foraminifera species commonly found in an offshore environment, indicates a predominantly marine section.

The overall environment of deposition during the accumulation of the Cowlitz Formation was complex. The lithologic changes over a short distance and the discontinuous nature of the beds in the formation reflect the variety of conditions that were extant contemporaneously during the period of deposition. The character of the sedimentary material indicates a tectonicly unstable area of low-lying coastal plain with numerous estuaries or embayments and near-sea-level swamps, adjacent to a shallow sea. The sedimentary material was washed into the basin from the east or southeast and, judging from the minerals present (mostly feldspar, quartz, and mica), it was derived from a schist or granitic terrane; however, the source could have been older sedimentary rocks.

The best outcrops of Cowlitz Formation sedimentary rocks in the area are along Coal Creek from the Eufaula Road bridge in the SE$\frac{1}{4}$ sec. 10, T. 8 N., R. 3 W., to near the center of sec. 27, T. 9 N., R. 3 W., and along Germany Creek from the SW. cor. sec. 6, T. 9 N., R. 3 W., to the SW. cor. sec. 24, T. 10 N., R. 4 W. A few good outcrops of shale and sandstone occur along Clark Creek in the W$\frac{1}{2}$ secs. 6 and 7 and NW$\frac{1}{4}$ sec. 18, T. 8 N., R. 2 W., and in the E$\frac{1}{2}$ sec. 12, T. 8 N., R. 2 W. Shale and massive sandstone beds crop out in the stream bottoms in the W$\frac{1}{2}$ sec. 30, T. 9 N., R. 2 W., and in the E$\frac{1}{2}$ sec. 25, T. 9 N., R. 3 W. Thin-bedded sandstone, siltstone, and shale crop out in the core of the Willapa Hills anticline from the headwaters of Germany Creek westward beyond the Elochoman River through the NW. cor. T. 10 N., R. 4 W., and the NE. cor. T. 10 N., R. 5 W.

Interfingering from the south with the sedimentary rocks in the southeast part of the area is a persistent volcanic unit. It is made up of basalt flows, flow breccia, pyroclastic material, and basaltic sandstone, gritstone, and pebble conglomerate. From just west of the Alder Bluff rock quarry, near where the north-south center line of sec. 7, T. 8 N., R. 3 W., intersects Highway 830, it extends eastward to the Chaufty rock quarry in the N½ sec. 15, T. 8 N., R. 3 W., where it dips beneath the valley floor. It crops out on the little knolls near the SE. cor. sec. 13, T. 8 N., R. 3 W., in roadcuts around the base of Columbia Heights, and at various places along the west side of the Cowlitz River to about the NW. cor. sec. 27, T. 9 N., R. 2 W., where it pinches out. It also extends northwestward along the west wall of Hazel Dell Valley into sec. 29, T. 9 N., R. 2 W., where it is truncated by a fault. The volcanic rocks that crop out around the base of Mount Solo have been assigned to this unit also.

The basalt flows in the unit are thin, commonly vesicular, and most of them have scoriaceous tops. Irregular blocky jointing is most common; however, a few flows have well-developed columnar jointing. The rocks are medium gray to dark gray on fresh surfaces and are bleached to a light gray by weathering. Vesicle fillings of both calcite and zeolite minerals are common. All 16 basalt samples from this unit examined petrographically are somewhat hypocrystalline

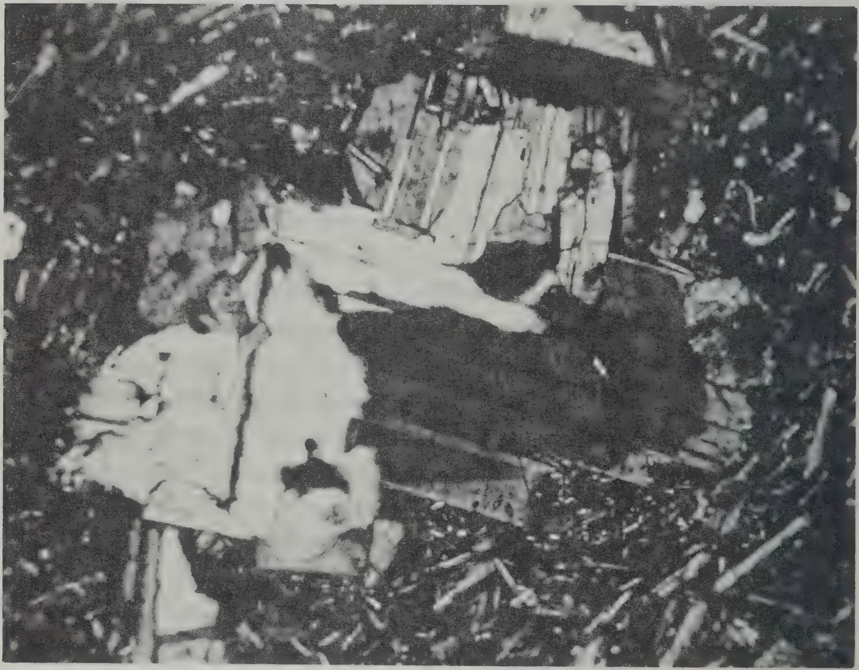


FIGURE 2. — Photomicrograph showing typical clot of plagioclase phenocrysts in volcanic flows of the Cowlitz Formation. This is also typical of Goble Volcanics. (X 50—crossed nicols.)

and porphyritic. Typically, the groundmass texture is intersertal; however, some flows are intergranular. Phenocrysts of plagioclase commonly occur in clots (Fig. 2), and in some flows the plagioclase crystals are aligned (Fig. 3). The average mineralogic composition is: plagioclase, 48 percent; augite and pigeonite, 28 percent; glass, 12 percent; opaque grains, 9 percent; alteration products (antigorite and iddingsite from olivine, and leucoxene), 3 percent.

The plagioclase varies from calcic andesine to calcic labradorite. In the sections studied, the groundmass plagioclase ranged from $Ab_{56}$-$An_{44}$ to $Ab_{42}$-$An_{58}$, but the average was between $Ab_{50}$-$An_{50}$ and $Ab_{48}$-$An_{52}$. The laths are subhedral to euhedral in outline, and many are corroded and embayed by augite. Twinning is carlsbad or albite or a combination of both. The phenocrysts are more calcic than the groundmass plagioclase, usually falling well within the labradorite range. One flow contains phenocrysts that are $Ab_{36}$-$An_{64}$. The phenocrysts are euhedral to subhedral in outline and commonly contain tiny inclu-

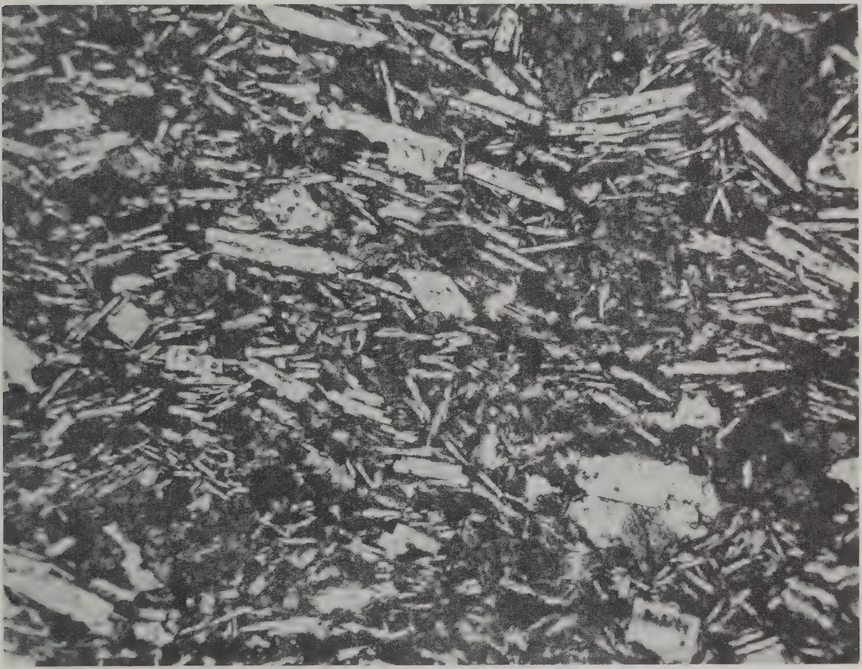


FIGURE 3.—Photomicrograph showing aligned plagioclase crystals in a volcanic flow of the Cowlitz Formation. (X 50—plane light.)

sions of augite and unidentified microlites. Ordinarily they show a combination of carlsbad and albite twinning, although it is common to find only albite present. Poor to well-developed zoning is common.

Most of the augite is scattered through the groundmass in the form of small equidimensional granules, although it also occurs as large euhedral to subhedral phenocrysts. Pigeonite is present only as large phenocrysts. Only one basalt flow in this unit had recognizable olivine; however, the clots of iddingsite and antigorite that occur in the rock are thought to have been derived from olivine.

Glass in the groundmass of the basalt flows is usually brown and in many instances is partially devitrified. In many of the basalts the glass is heavily charged with a black opaque dust thought to be magnetite. Opaque mineral grains, most of which are probably magnetite, are an important part of the groundmass. The opaques usually are euhedral to anhedral in outline, the former being mostly cubical, and in a few sections skeletal ilmenite crystals are common.

The one flow breccia examined consists mainly of plagioclase and pyroxene grains and rock fragments, all engulfed in a matrix of cloudy brown, almost totally devitrified glass. Most of the plagioclase grains, especially the larger euhedral crystals, are severely corroded. The clear, unaltered grains are in the composition range (about $Ab_{30}$-$An_{70}$) between calcic labradorite and sodic bytownite. Euhedral pyroxene crystals, which are pigeonite, are more altered than the anhedral pyroxene grains. Most of the opaque mineral grains are irregular in shape. There are numerous small ragged clots of calcite present also. The glass has a blotchy, cloudy, mottled appearance, caused by its devitrification, and contains small but distinct spherulitic aggregates of an unidentified mineral, presumably a zeolite. Pieces of basalt and glassy material make up the rock fragments, which are easily seen because of sharp, well-defined contacts with matrix material.

Lithologically and petrographically this unit is similar to the type Goble Volcanics as described by Wilkinson, Lowry, and Baldwin (1946, p. 5-7) and to the Goble Volcanic Member of the Cowlitz Formation as described by Henriksen (1956, p. 82). It is interpreted as being a tongue of the Goble Volcanics interfingering with the Cowlitz Formation from the south.

Age and correlation.—Weaver (1912, p. 13) originally considered the Cowlitz Formation to be slightly older than the upper Eocene Tejon Formation of California. Dickerson (1915, p. 50-51), after working on the Cowlitz invertebrate fauna, correlated it with the Tejon, and his work was later confirmed by Weaver (1916b). Beck (1943, p. 591) found that the foraminiferal assemblage from the upper part of the Cowlitz Formation correlated with faunas of the Coaledo

Formation in Oregon and the Tejon Formation in California. Henriksen (1956, p. 44, 57) correlated the Cowlitz Formation with the Skookumchuck Formation and the upper part of the McIntosh Formation.

Following are lists of invertebrate megafossils collected from the Cowlitz Formation in the Kelso-Cathlamet area and identified by the author.

Location 134. Railroad cut in the NW¼ sec. 12, T. 8 N., R. 2 W.

Pelecypoda
- *Glycymeris eocenica* (Weaver)
- *Ostrea idriaensis* Gabb

Location 154. Old roadcut in the NE¼ sec. 25, T. 9 N., R. 3 W.

Pelecypoda
- *Nuculana cowlitzensis* (Weaver and Palmer)

Location 159. Outcrop along creek in the NW¼ sec. 32, T. 9 N., R. 2 W.

Pelecypoda
- *Acila* (*Truncacila*) *decisa* (Conrad)
- *Nuculana cowlitzensis* (Weaver and Palmer)

Location 188. Outcrop along creek in the NW¼SE¼ sec. 7, T. 8 N., R. 2 W.

Pelecypoda
- *Acila* (*Truncacila*) *decisa* (Conrad)
- *Nuculana cowlitzensis* (Weaver and Palmer)
- *Nuculana* cf. *N. washingtonensis* (Weaver)
- *Macrocallista* sp.

Gastropoda
- *Turritella uvasana* Conrad

Location 51. Along the banks of Coal Creek near the center of the E½ sec. 11, T. 8 N., R. 3 W.

Pelecypoda
- *Pteria clarki* Weaver and Palmer
- *Volsella kelsoensis* (Weaver and Palmer)
- *Microcallista* (*Costacallista*) *conradiana* (Gabb)
- *Crassatellites dalli* Weaver
- *Pitar californiana* (Conrad)
- *Loxocardium* (*Schedocardia*) *brewerii* (Gabb)
- *Nuculana cowlitzensis* (Weaver and Palmer)
- *Ostrea idriaensis* Gabb

Pelecypoda—Continued
*Gari columbiana* (Weaver and Palmer)
*Venericardia hornii* (Gabb)
*Pecten (Chlamys) cowlitzensis* Weaver
*Solena columbiana* (Weaver and Palmer)
*Tivelina vaderensis* (Dickerson)
Gastropoda
*Whitneyella* cf. *W. washingtoniana* (Weaver)
*Exilia* sp.
*Turritella uvasana* Conrad
*Polinices* sp.
*Diodora stillwaterensis* (Weaver and Palmer)
*Ficopsis cowlitzensis* (Weaver)
*Crepidula pileum* (Gabb)
*Calyptraea diegoana* (Conrad)
Scaphopoda
*Dentalium stramineum* Gabb
Arthropoda
*Balanus* sp.

Location 55. Along the west bank of Coal Creek in the NW¼SW¼ sec. 11, T. 8 N., R. 3 W.

Pelecypoda
*Mytilus* sp.
Gastropoda
*Calyptraea diegoana* (Conrad)
*Cerithiopsis vaderensis* (Dickerson)
*Polinices* sp.
*Siphonalia* cf. *S. washingtonensis* (Weaver)

Location 57A. Along the west bank of Harmony Creek, 0.4 mile from its junction with Coal Creek, in the NW¼SE¼ sec. 10, T. 8 N., R. 3 W.

Pelecypoda
*Ostrea idriaensis* Gabb
*Tivelina vaderensis* (Dickerson)
*Venericardia hornii* (Gabb)
Gastropoda
*Turritella uvasana* Conrad

Location 519. Along the channel of Coal Creek about 0.2 mile below the bridge over Coal Creek in the NW¼SE¼ sec. 2, T. 8 N., R. 3 W.

Pelecypoda
- Pitar (Lamelliconcha) clarki (Dickerson)
- Solena columbiana (Weaver and Palmer)

Gastropoda
- Ficopsis cowlitzensis (Weaver)

Scaphopoda
- Dentalium stramineum Gabb

Location 520. In the streambed of Coal Creek 0.2 mile above the bridge across Coal Creek in the SE¼NW¼ sec. 2, T. 8 N., R. 3 W.

Pelecypoda
- Venericardia hornii (Gabb)
- Loxocardium (Schedocardia) brewerii (Gabb)
- Tivelina vaderensis (Dickerson)
- Solena columbiana (Weaver and Palmer)
- Gari sp.
- Glycymeris sagittata (Gabb)
- Pitar sp.

Gastropoda
- Turritella uvasana Conrad
- Polinices sp.
- Calyptraea diegoana (Conrad)
- Crepidula pileum (Gabb)

Location 520A. In the streambed 50 feet north of locale 520.

Pelecypoda
- Ostrea idriaensis Gabb

Gastropoda
- Calyptraea diegoana (Conrad)

Location 521. In the streambed of Coal Creek 0.3 mile above the bridge across Coal Creek in the SE¼NW¼ sec. 2, T. 8 N., R. 3 W.

Pelecypoda
- Pitar sp.

Gastropoda
- Ficopsis cowlitzensis (Weaver)

Scaphopoda
- Dentalium stramineum Gabb

Location 523. In the streambed of Coal Creek about on the section line between sec. 2, T. 8 N., R. 3 W., and sec. 35, T. 9 N., R. 3 W.

Pelecypoda
*Tivelina vaderensis* (Dickerson)
*Ostrea idriaensis* Gabb
*Gari* sp.
Gastropoda
*Polinices* sp.

Foraminiferal assemblages from the area were examined by W. W. Rau (oral communication, 1963) and found to be typical of those from Beck's (1943) type Cowlitz. Following are lists of Foraminifera that were found in the Cowlitz Formation during the course of this study.

Location 1158. Auger hole along Clark Creek directly under the Bonneville transmission lines, in sec. 12, T. 8 N., R. 3 W.

*Robulus* spp.
*Dentalina* cf. *D. dusenburyi* Beck
*Lagena* cf. *L. substriata* Williamson
*Globulina inequalis* Reuss
*Nonion* cf. *N. applini* Howe and Wallace
*Cibicides natlandi* Beck

Location 1159. Auger hole along Clark Creek about 900 feet north of locale 1158, in sec. 2, T. 8 N., R. 3 W.

*Cyclammina pacifica* Beck
*Quinqueloculina imperialis* Hanna and Hanna
*Biloculinella cowlitzensis* Beck
*Robulus* spp.
*Globobulimina pacifica* Cushman
*Eponides yeguaensis* Weinzierl and Applin
*Ceratobulimina washburnei* Cushman and Schenck
*Cibicides* cf. *C. elmaensis* Rau
*Cibicides haydoni* (Cushman and Schenck)

Location 1160. Auger hole along the McKee Road about 0.4 mile from the Delameter Road in the extreme SW. cor. sec. 19, T. 9 N., R. 2 W.

*Cyclammina* sp.
*Nonion* sp.
*Bulimina ovata cowlitzensis* Beck
*Bolivina basisenta* Cushman and Stone

Location 155. Outcrop along a creek bank in the NW¼SE¼ sec. 25, T. 9 N., R. 3 W.

*Robulus holcombensis* Rau
*Dentalina* spp.
*Nonion inflatum* Cushman and Ellisor
*Plectofrondicularia packardi multilineata* Cushman and Simonson
*Bulimina ovata cowlitzensis* Beck
*Ellipsonodosaria cocoaensis* (Cushman)
*Cibicides hodgei* Cushman and Schenck

Location 626. Along Germany Creek in the SE¼NW¼ sec. 36, T. 10 N., R. 4 W.

*Ammobaculites* sp.
*Robulus* spp.
*Dentalina* spp.
*Nonion* cf. *N. applini* Howe and Wallace
*Amphimorphina jenkinsi* (Church)
*Bulimina ovata cowlitzensis* Beck
*Bulimina schencki* Beck
*Bulimina microcostata* Cushman and Parker
*Bolivina basisenta* Cushman and Stone
*Bolivina* cf. *B. kleinpelli* Beck
*Angulogerina hannai* Beck
*Gyroidina condoni* (Cushman and Schenck)
*Eponides yeguaensis* Weinzierl and Applin
*Alabamina wilcoxensis californica* Mallory
*Globigerina* sp.
*Cibicides haydoni* (Cushman and Schenck)
*Cibicides* cf. *C. cushmani* Nuttall

Location 628. Outcrop along Germany Creek in the SW¼SW¼ sec. 25, T. 10 N., R. 4 W.

*Robulus* spp.
*Robulus* cf. *R. welchi* Church
*Nonion* cf. *N. applini* Howe and Wallace
*Plectofrondicularia kerni* Cook
*Amphimorphina jenkinsi* (Church)
*Bulimina microcostata* Cushman and Parker

*Bulimina schencki* Beck
*Bolivina basisenta* Cushman and Stone
*Bolivina* cf. *B. kleinpelli* Beck
*Angulogerina hannai* Beck
*Gyroidina condoni* (Cushman and Schenck)
*Cassidulina globosa* Hantken
*Globigerina* sp.
*Cibicides mcmastersi* Beck

Location 630. Along a creek bank near the center of the S½S½ sec. 24, T. 10 N., R. 4 W.

*Robulus* spp.
*Nodosaria* sp.
*Pseudoglandulina conica* (Neugeboren)
*Lagena conscripta* Cushman and Barksdale
*Ellipsonodosaria cocoaensis* (Cushman)
*Valvulineria jacksonensis welcomensis* Mallory
*Gyroidina condoni* (Cushman and Schenck)
*Alabamina kernensis* Smith
*Cassidulina globosa* Hantken
*Cibicides natlandi* Beck
*Cibicides hodgei* Cushman and Schenck

Location Ry 10. Cliff along Germany Creek just above the bridge near the N-S center line but just in the NW¼SW¼SE¼ sec. 36, T. 10 N., R. 4 W.

*Robulus* spp.
*Marginulina subbullata* Hantken
*Dentalina* spp.
*Pseudoglandulina conica* (Neugeboren)
*Lagena conscripta* Cushman and Barksdale
*Guttulina irregularis* (d'Orbigny)
*Plectofrondicularia searsi* Cushman, R. E. and K. C. Stewart
*Angulogerina hannai* Beck
*Globigerina* sp.
*Cibicides hodgei* Cushman and Schenck

Location Ry 12. Along the east bank of the Elochoman River where it makes a sharp turn to the south in the SW¼SE¼ sec. 13, T. 10 N., R. 5 W.

*Robulus* spp.

Dentalina spp.
Saracenaria sp.
Bulimina ovata cowlitzensis Beck
Chilostomella sp.

The Cowlitz Formation in the Kelso-Cathlamet area is considered to be uppermost Eocene in age and is correlated with the Skookumchuck Formation of Snavely and others (1958) in the Centralia-Chehalis area; with Henriksen's (1956) Olequa Creek Member of the Cowlitz Formation in the Vader-Pe Ell area; and with the upper part of the Nestucca Formation of northwest Oregon (W. W. Rau, oral communication, 1963). The foraminiferal assemblages indicate that the Cowlitz Formation in the area represents the Bulimina schencki-Plectofrondicularia cf. P. jenkinsi Zone of Rau (1958).

Contact relations. — The lower contact of the Cowlitz Formation, with the Metchosin(?) of Henriksen (1956) in the Kelso-Cathlamet area, is exposed in the core of the Willapa Hills anticline, in the S½ sec. 7, T. 10 N., R. 4 W., but was not studied. The upper contact, with the Goble Volcanics, is a transitional or interfingering one, consisting of a zone of intercalated volcanic and sedimentary units between the sedimentary rocks of the Cowlitz Formation and the volcanic rocks of the Goble. The two formations are conformable. In the eastern part of the area, where their contact relations can be seen, the Columbia River Basalt unconformably overlies the Cowlitz Formation.

## Goble Volcanics

It is proposed herein that the name "Goble Volcanic Series" be changed to "Goble Volcanics," in accordance with Article 9f. of the Code of Stratigraphic Nomenclature (Am. Assoc. Petrol. Geol. Bull., vol. 45, no. 5, p. 651). This eliminates the use of a time-stratigraphic term in a rock-stratigraphic sense. E. M. Baldwin (written communication, 1963), who did much of the early work on the formation, concurs in this change and states further that the unit has never been considered to be a series as defined in the Code of Stratigraphic Nomenclature. The name "Goble Volcanic Series" was first proposed by Warren, Norbisrath, and Grivetti (1945) for a thick sequence of basaltic flows and pyroclastic rocks that crop out on both sides of the Columbia River between Deer Island, near Woodland, and Walker Island, west of Longview. The formation was named for the excellent outcrops in the vicinity of Goble, Oregon. Wilkinson, Lowry, and Baldwin (1946) presented a detailed petrographic description of Goble rocks that crop out in both Oregon and Washington. They also show the structure of the Goble rocks along Highway U.S. 99 from about 3 miles north of Woodland north to Kelso (Wilkinson, Lowry, and Baldwin, 1946, p. 6). Henriksen (1956) mapped a series of flows, flow breccias, and pyroclastic rocks in the Vader area that he called the Goble Volcanic Member of the Cowlitz Formation. Warren, Norbisrath, and Grivetti (1945) and Wilkinson, Lowry, and Baldwin (1946, p. 5) indicate that in the type area the formation is more than 5,000 feet thick. Henriksen (1956, p. 59) thinks it is less than 1,000 feet thick in the Vader area.

Approximately 1,000 feet of Goble rocks are present in the Kelso-Cathlamet area. They occur along the east edge of the area in sec. 36, T. 9 N., R. 2 W., and sec. 1, T. 8 N., R. 2 W., and in an irregular northwest-trending band between Delameter Creek and the Elochoman River. The formation consists of basalt flows, flow breccias, and pyroclastic material, along with scattered intercalated sedimentary beds.

The basalt flows of the Goble Volcanics in the area are usually thin and have vesicular to scoriaceous tops. Jointing is most commonly blocky, but well-developed columns occur in some flows. On fresh surfaces the basalt is dark gray to black, and it weathers light gray.

All of the Goble Volcanics flow rocks that were examined petrographically are fine-grained basalt. They are hypocrystalline and slightly to distinctly porphyritic, and they have a groundmass ranging from intergranular through intersertal to slightly hyalo-ophitic; intersertal being the most common texture. In many of the thin sections examined, the plagioclase phenocrysts were grouped together in clots, giving a glomeroporphyritic texture. Phenocrysts other than plagioclase are pigeonite, augite, magnetite, and altered olivine. The phenocrysts make up from less than 5 percent to about 40 percent of the basalt, the average being about 15 percent. The average mineral composition of the rocks examined is: plagioclase, 53 percent; augite and pigeonite, 27 percent; olivine and associated alteration products (mostly iddingsite and antigorite), 5 percent; opaques, 10 percent; and glass, less than 5 percent.

The plagioclase varies from sodic labradorite to sodic bytownite. In the sections examined, groundmass plagioclase averages about $Ab_{48}$-$An_{52}$. The crystal laths, which are euhedral to subhedral in form, usually have corroded edges. Twinning is mostly of the albite type, but both carlsbad and a combination of albite and carlsbad are common. In one section, what appears to be a baveno twin is present. The phenocrysts are mostly calcic labradorite; however, because of strong zoning their composition is not uniform. In a few sections the cores of the phenocrysts are sodic bytownite and the rims calcic labradorite. The phenocrysts are usually euhedral where they occur singly, but where they occur in clusters they tend to be subhedral. The commonest crystal form is lathlike, but tabular grains are present in every section. The phenocrysts are usually twinned in either the albite or carlsbad forms, or a combination of the two. They are strongly zoned regardless of the type of crystal or twinning, the cores being more calcic than the rims.

Augite is present mostly as small equidimensional anhedral granules scattered more or less uniformly through the groundmass. Augite is not abundant as large euhedral to subhedral phenocrysts; however, pigeonite is quite abundant as large phenocrysts. Some of the pigeonite crystals are twinned.

Opaque minerals are all black under reflected light. They are equant and euhedral to subhedral in outline and are usually scattered uniformly throughout the section.

Glass in the groundmass of the basalts is both cloudy and clear brown. It is randomly distributed through the sections in irregular-shaped masses or clots.

In a few sections, olivine is recognizable, but most of it has been altered to iddingsite or antigorite. It is present as phenocrysts that have been incompletely altered, leaving the olivine remnants more or less scattered through the alteration products.

*Age and correlation*. — The Goble Volcanics has been assigned to the upper Eocene and possibly lower Oligocene by Wilkinson, Lowry, and Baldwin (1946, p. 9) at its type locality. The following fossils were collected from a roadcut on the east side of the old Pacific Highway 0.6 mile south of the Coweman River bridge by Wilkinson, Lowry, and Baldwin (1946, PF-9, p. 10) and identified by E. M. Baldwin:

*Nuculana cowlitzensis* (Weaver and Palmer)
*Pteria clarki* Weaver and Palmer
*Ostrea* sp.
*Volsella (Brachidontes) cowlitzensis* (Weaver and Palmer)
*Crassatellites stillwaterensis* Weaver and Palmer
*Pitar califoriana* (Conrad)
*Pitar eocenica* (Weaver and Palmer)
*Pachydesma* cf. *P. crowderi* Weaver
*Gari cowlitzensis* (Weaver and Palmer)
*Gari columbiana* (Weaver and Palmer)

*Solena columbiana* (Weaver and Palmer)
*Spisula* cf. *S. packardi* var. *yokamensis* Turner
*Corbula* sp.
*Dentalium* sp.
cf. *Cymatium* sp.
cf. *Polinices hornii* (Gabb)
*Ficopsis* sp.

Fossils found higher in the section, in a roadcut along the old Pacific Highway 1.5 miles south of the bridge across the Coweman River, collected by Wilkinson, Lowry, and Baldwin (1946, PF-10, p. 10) and identified by Baldwin are:

*Nuculana* cf. *N. cowlitzensis* (Weaver and Palmer)
*Volsella* (*Brachidontes*) *cowlitzensis* (Weaver and Palmer)
*Pachydesma crowderi* Weaver
*Tellina* cf. *T. cowlitzensis* Weaver
cf. *Bonellitia paucivaricata* (Gabb)
*Polinices* sp.

Both of these localities described by Baldwin are in the interfingering or transitional phase between the Cowlitz Formation and the Goble Volcanics, thus the base of the Goble is considered to be upper Eocene in age.

Foraminifera collected from sedimentary interbeds near the top of the Goble Volcanics on Abernathy Mountain and identified by W. W. Rau (oral communication, 1963) are as follows:

Location 612. In a ditch of the Mosquito Creek Road, SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 5, T. 9 N., R. 3 W.

*Triloculina* sp.
*Pseudoglandulina* sp.
*Lagena conscripta* Cushman and Barksdale
*Guttulina irregularis* (d'Orbigny)
*Guttulina frankei* Cushman and Ozawa
*Guttulina problema* d'Orbigny
*Sigmomorphina schencki* Cushman and Ozawa
*Nonion* cf. *N. applini* Howe and Wallace
*Elphidium* cf. *E. minutum* Cushman
*Entosolenia* sp.
*Bolivina* cf. *B. jacksonensis* Cushman and Applin

*Valvulineria willapaensis* Rau
*Gyroidina orbicularis planata* Cushman
*Cassidulina* cf. *C. crassipunctata* Cushman and Hobson
*Pullenia salisburyi* R. E. and K. C. Stewart
*Globigerina* sp.
*Anomalina californiensis* Cushman and Hobson
*Cibicides elmaensis* Rau
*Cibicides* sp.

Location 611. In a ditch of the Abernathy Truck Trail, NE¼ sec. 29, T. 10 N., R. 3 W.

*Lagena costata* (Williamson)
*Pseudopolymorphina* cf. *P. ligua* (Roemer)
*Nonion planatum* Cushman and Thomas
*Nonion halkyardi* Cushman
*Elphidium smithi* Cushman and Dusenbury
*Bolivina* sp.
*Valvulineria* willapaensis Rau
*Gyroidina soldanii* d'Orbigny
*Cassidulina* cf. *C. armosa* Bandy
*Cibicides baileyi* Beck
*Cibicides* cf. *C. sassei* Cole
*Cibicides lobatus* (d'Orbigny)

Location 631. In a ditch of the Abernathy Truck Trail, SW¼NW¼ sec. 28, T. 10 N., R. 3 W.

*Quinqueloculina imperialis* Hanna and Hanna
*Pseudoglandulina* cf. *P. inflata* (Bornemann)
*Pseudopolymorphina* cf. *P. ligua* (Roemer)
*Nonion planatum* Cushman and Thomas
*Nonion halkyardi* Cushman
*Elphidium smithi* Cushman and Dusenbury
*Valvulineria willapaensis* Rau
*Gyroidina soldanii* d'Orbigny
*Cassidulina* cf. *C. armosa* Bandy
*Cibicides* cf. *C. sassei* Cole
*Cibicides baileyi* Beck

According to W. W. Rau (oral communication, 1963), the faunas from locations 611 and 631 are typical of the Gries Ranch or lower Refugian, whereas that of location 612 is a little higher in the section, possibly upper Refugian. It is noteworthy that at location 612, which appears to be well into the Oligocene, Goble-type volcanic rocks apparently are still abundant in the section.

On the basis of the fossils found in the sedimentary interbeds at both the base and top of the Goble Volcanics in the Kelso-Cathlamet area, the formation is assigned an age of late Eocene to early Oligocene.

Contact relations. — Both upper and lower contacts of the Goble are transitional, interfingering with the Eocene sedimentary rocks of the Cowlitz Formation below and Oligocene sedimentary rocks above. In the northern part of the area, where the two formations are in contact, the Columbia River Basalt unconformably overlies the Goble.

## Oligocene Sedimentary Rocks

At the northwest corner of the area a section of massive dark- to light-gray siltstones is exposed along the Elochoman River near Camp 2. Below is a list of Foraminifera identified by W. W. Rau (oral communication, 1963) and assigned by him to the Refugian.

Location 84. In a cliff along the east bank of the Elochoman River, SW¼SW¼ sec. 24, T. 10 N., R. 5 W.

Pseudoglandulina sp.
Guttulina irregularis (d'Orbigny)
Sigmomorphina schencki Cushman and Ozawa
Nonion halkyardi Cushman
Nonion sp.
Elphidium cf. E. minutum Cushman
Elphidium cf. E. smithi Cushman and Dusenbury
Plectofrondicularia searsi Cushman, R. E. and K. C. Stewart
Bolivina cf. B. jacksonensis Cushman and Applin
Angulogerina sp.
Gyroidina orbicularis planata Cushman
Ceratobulimina washburnei Cushman and Schenck
Cassidulina galvinensis Cushman and Frizzell
Cibicides elmaensis Rau

Contact relations. — The exact relation of the Oligocene sedimentary rocks to the Goble Volcanics was not observed; however, the two formations appear to be conformable. The unit is unconformably overlain by the Columbia River Basalt.

## Columbia River Basalt

The name "Columbia River Basalt" was first used by Russell (1893, p. 20-22) to include basaltic rocks of early, middle, and late Tertiary age in the Pacific Northwest. In recent years, however, the trend has been to restrict the name to basalt flows of Miocene age.

Columbia River Basalt has been described and mapped in northwestern Oregon by Treasher (1942), Libbey, Lowry, and Mason (1945), Warren, Norbisrath, and Grivetti (1945), Wilkinson, Lowry, and Baldwin (1946), Corcoran and Libbey (1956), and Trimble (1957 and 1963); and in southwestern Washington by Snavely and others (1951), Henriksen (1956), and Snavely and others (1958).

The Columbia River Basalt may be as much as 1,400 feet thick in the Kelso-Cathlamet area. It caps the low rolling hills and north-south-trending ridges that are truncated by the Columbia River between Longview and Cathlamet, and it extends 5 miles northward from the river at Coal Creek and 11 miles along the Elochoman River. The formation is composed of basalt containing a few sandstone and conglomerate interbeds. Some of the basalt flows poured out onto a wet surface or into streams and ponds, with the result that palagonite and spiracles occur locally. The best exposures are seen along Highway U.S. 830 between Alder Bluff quarry, in the SW¼ sec. 8, T. 8 N., R. 3 W., and Abe Creek, in the NE¼NW¼ sec. 18, T. 8 N., R. 5 W. Other good outcrops occur along the Eufaula Road near the center of sec. 10, T. 8 N., R. 3 W; along the Coal Creek Road in the SW¼ sec. 27, T. 9 N., R. 3 W.; at an old crusher site in the SE¼ sec. 6, T. 8 N., R. 2 W.; along the Columbia Heights Road in the NW¼ sec. 16, T. 8 N., R. 2 W.; along the Bonneville powerline in the SE¼ sec. 4, T. 8 N., R. 2 W.; and at numerous places along the Mill Creek, Abernathy Creek, and Germany Creek roads.

The Columbia River Basalt usually stands out in bold outcrops along the stream valleys. Jointing in the basalt is typically columnar, although irregular blocky or hackly and platy varieties are also common. In a few flows the columns are curved, such as those at the top of the Alder Bluff rock quarry in sec. 8, T. 8 N., R. 3 W. The fresh rock is dark gray to black, dense and hard, and

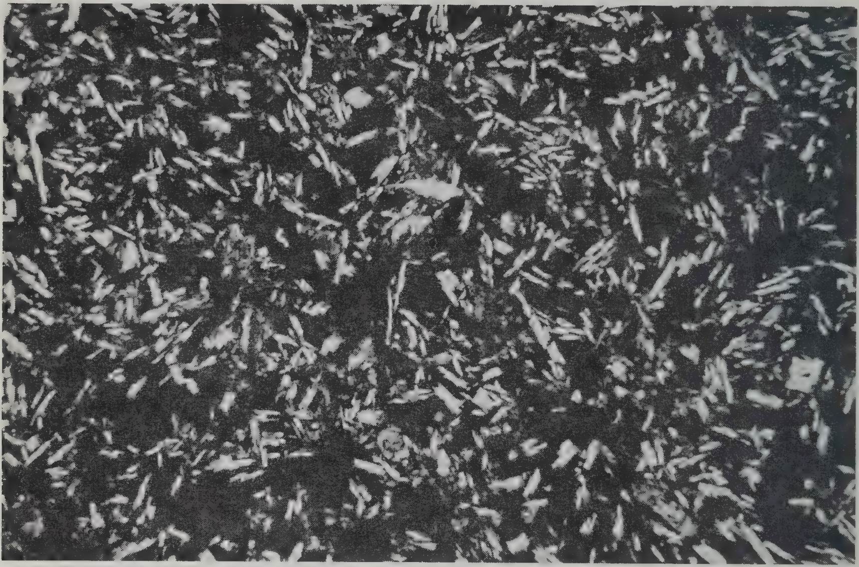


FIGURE 4.—Photomicrograph of Columbia River Basalt. White crystals are plagioclase and augite. Black area is volcanic glass heavily charged with an opaque mineral dust, probably magnetite. (X 18—plane light.)

typically it looks slightly glassy. Upon weathering, it turns to various hues of gray, yellow, brown, and rust red.

Typically, the Columbia River Basalt is hyalo-ophitic textured. Its most striking mineralogical feature is the remarkable abundance of glass (Fig. 4); one thin section contained 63 percent. Generally, the sections contain between 30 and 40 percent glass, 40 and 45 percent plagioclase, 25 and 30 percent augite, not over 10 percent opaques, less than 1 percent olivine, and not more than 5 percent alteration minerals. A few of the samples studied contained zeolites. The plagioclase varies in composition from $Ab_{52}$-$An_{48}$ to $Ab_{35}$-$An_{65}$; however, most of it is between $Ab_{50}$-$An_{50}$ and $Ab_{45}$-$An_{55}$. Less than 1 percent of the plagioclase occurs as phenocrysts. The individual crystals are euhedral to subhedral in outline and are mostly twinned according to the albite law. Combined carlsbad-albite twins are common also.

Augite is present mostly as granules, and pigeonite commonly occurs as phenocrysts. Glass is usually brown and heavily charged with opaque magnetite(?) dust. Opaque grains are both equant and bladelike euhedra. Alteration minerals, such as antigorite(?) and iddingsite(?), are in clots and probably formed by the alteration of olivine.

TABLE 2.—Analysis of Columbia River Basalt from Alder Bluff, 1,750 ft. E., 1,000 ft. N. of SW. cor., sec. 8, T. 8 N., R. 3 W.[1]

| | Percent |
|---|---|
| $SiO_2$ | 51.55 |
| $Al_2O_3$ | 14.84 |
| $Fe_2O_3$ | 1.61 |
| FeO | 9.02 |
| MgO | 6.81 |
| CaO | 10.52 |
| $Na_2O$ | 2.41 |
| $K_2O$ | 0.66 |
| $H_2O+$ | 0.40 |
| $H_2O-$ | 0.23 |
| $TiO_2$ | 1.62 |
| $P_2O_5$ | 0.23 |
| MnO | 0.18 |
| $CO_2$ | 0.02 |
| Cl | 0.01 |
| F | 0.03 |
| Subtotal | 100.14 |
| Less O | 0.01 |
| Total | 100.13 |

---

[1] Analyst: Elaine L. Munson, U.S. Geological Survey.

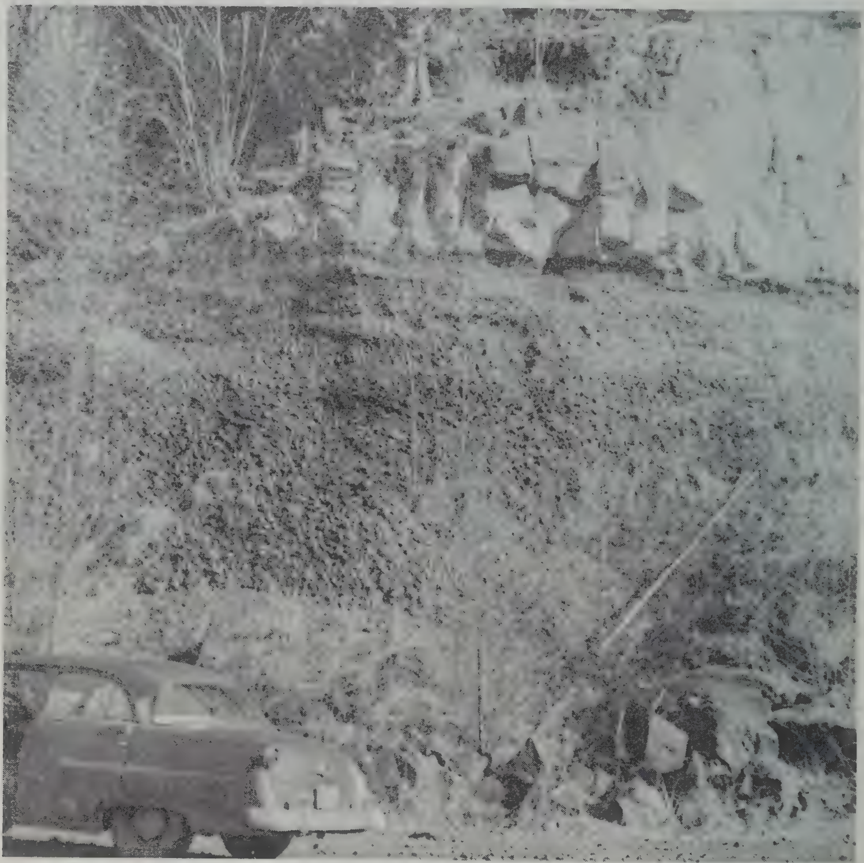


FIGURE 5.—Interflow conglomerate in Columbia River Basalt. Sec. 10, T. 8 N., R. 3 W., along the Eufaula Road.

Two types of sedimentary interbeds were observed between the basalt flows. The most common are sandstone layers that are scattered throughout the section and increase in number to the west. The second type is a coarse pebble to cobble conglomerate (Fig. 5) that is typified in exposures along the Eufaula Road in sec. 10, T. 8 N., R. 3 W. Here the conglomerate is made up of well-rounded volcanic rock cobbles and pebbles that have been almost completely altered to clay. The original volcanic texture has been preserved in the clay, indicating that most of the clasts were derived from a porphyry.

Economically, the Columbia River Basalt is probably the most important formation in the area. Not only is it used extensively for road metal, riprap, and jetty stone; it is the parent rock from which the ferruginous bauxite of southwestern Washington has been formed.

Age and correlation.—No fossils were found associated with the sedimentary rock interbeds of the Columbia River Basalt. The formation is assigned to the Miocene on the basis of lithologic and stratigraphic similarities to known Miocene rocks to the west and south. Westward, the formation, by a decrease in basalt flows and an increase in sedimentary rocks, passes laterally into the Astoria Formation.

Contact relations.—The Columbia River Basalt unconformably overlies the Cowlitz Formation in the eastern part of the area, the Goble Volcanics in the northern part of the area, and massive Oligocene siltstones near Camp 2 in the northwest part of the area. Overlying the formation unconformably in the southern part of the area are two silt units that may be correlative with the Portland Hills Silt (Lowry and Baldwin, 1952, p. 7-14).

## Troutdale Formation

The name Troutdale was first mentioned by Hodge in 1933 (p. 157), and was formally proposed by him in 1938 (p. 873) to describe conglomerate and sandstone beds that crop out near Troutdale, Oregon. Treasher (1942, p. 7) described Troutdale rocks in the Portland area. Wilkinson, Lowry, and Baldwin (1946, p. 24) mapped conglomerate and sandstone beds in the St. Helens, Oregon, quadrangle as Troutdale and further suggested that massive silt deposits that overlie the conglomerate should be included in the formation. Lowry and Baldwin (1952, p. 7-14) described the Troutdale in the lower Columbia River valley and formally proposed the name Portland Hills Silt Member of the Troutdale for the massive silt overlying the conglomerates, and then designated the Portland Hills as the type locality. They estimated that the Troutdale Formation may be nearly 2,000 feet thick in the Portland Basin. Trimble (1957, and 1963, p. 29) mapped Troutdale on both sides of the Columbia River in the Portland-Vancouver area and estimated that the formation is over 1,100 feet thick.

A unit of moderately consolidated conglomerate, sandstone, and silt approximately 500 feet thick was mapped in the Kelso 7½ minute quadrangle. Mapping of the unit was not carried into the area covered by reconnaissance mapping; however, there are several small patches of Troutdale plastered up against the Columbia River valley wall at various places.

The Troutdale Formation is made up of two members in the Kelso area, a coarse conglomerate lower member and a fine sandy to silty upper member. The conglomerate is the more extensively exposed and more easily observed. It is poorly bedded, and is commonly crossbedded and channeled. Small lenticular crossbedded coarse-grained sandstone beds are common in it. The rock fragments in the conglomerate are predominantly well rounded. In the mapped area, boulders are exclusively basalt, pebbles and cobbles are mostly basalt, quartzite is common, and crystalline fragments are rare. Most of the basalt fragments have a weathering rind, which on most of them is only thick enough to discolor the surface of the rock; however, a few of the fragments have a rind as much as $\frac{1}{4}$ inch in thickness.

The largest rock fragment found in the Troutdale was a basalt boulder 350 mm in diameter. The largest quartzite fragment was 175 mm in diameter. In a 43.5-pound random sample taken from a gravel pit in the SW$\frac{1}{4}$ sec. 36, T. 8 N., R. 2 W., 58 percent by weight was cobbles, 31 percent was pebbles, 2 percent was granules, 7 percent was sand, and 2 percent was silt and clay. Identification of 655 pebbles and cobbles in a random sample taken from a roadcut along Glenwood Drive, in the W$\frac{1}{2}$ sec. 21, T. 8 N., R. 2 W., at an elevation of approximately 180 feet above sea level, showed that there were 16 quartzite fragments, which constituted 5 percent of the sample by weight. The quartzite fragments varied in size from 14 to 67 mm; only two of them were over 64 mm. There were three crystalline fragments, all of which were about 15 mm in diameter. The remaining 636 fragments were basaltic in origin (mostly Columbia River Basalt rock types) and ranged in size from 4 to 135 mm. Twenty-five of these were cobbles. Overall, the sample contained 27 cobbles, which made up 53 percent; the rest of the fragments were pebbles.

TABLE 3.—Screen analysis of Troutdale sand taken from roadcut along Glenwood Drive, W$\frac{1}{2}$ sec. 21, T. 8 N., R. 2 W. Elevation approximately 200 feet

| Grain size (mm) | Percent |
|---|---|
| 1 - 1/2 | 0.6 |
| 1/2 - 1/4 | 39.6 |
| 1/4 - 1/8 | 49.0 |
| 1/8 - 1/16 | 5.8 |
| Less than 1/16 | 4.8 |
| Loss on screening | 0.2 |
| Total | 100.0 |

The sand grains are mostly quartz, feldspar, rock fragments, and mica. The grains are angular; many of them still retain their original crystal form. The feldspars are tabular and lathlike, and the ferromagnesian minerals are prismatic.

The silty member of the Troutdale is typically light gray and is mineralogically similar to the sand, with the exception that more clay is present.

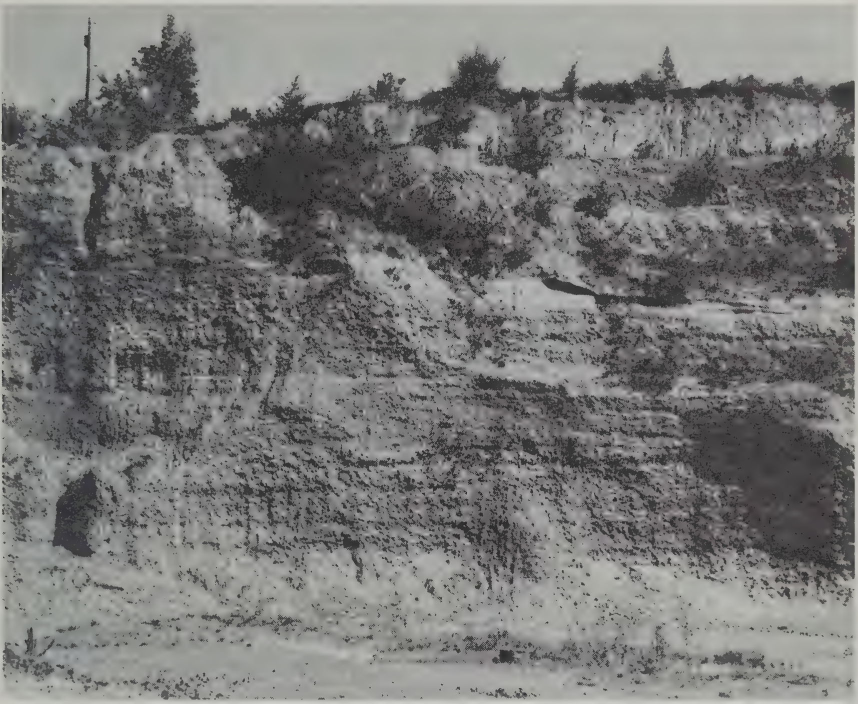


FIGURE 6.—Troutdale conglomerate exposed in a gravel pit, sec. 21, T. 8 N., R. 2 W.

Good exposures of Troutdale conglomerate can be seen in the gravel pits at the NW. corner of the SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 21, T. 8 N., R. 2 W. (Fig. 6); in the SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 23, T. 8 N., R. 2 W.; and in the SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 36, T. 8 N., R. 2 W. Conglomerate and sandstone exposures are numerous in the cuts of the various roads that cross Columbia Heights and Beacon Hill in secs. 15, 16, 17, 21, 22, 27, and 28, T. 8 N., R. 2 W. Conglomerate and silt exposures can be seen along Rocky

Point Loop Road in secs. 13, 14, and 24, T. 8 N., R. 2 W.; along the Mount Brynion Road in secs. 23, 24, and 26, T. 8 N., R. 2 W.; along the Harris Road in secs. 25 and 26, T. 8 N., R. 2 W.; and in the Davis Terrace area in secs. 35 and 36, T. 8 N., R. 2 W., and in sec. 1, T. 7 N., R. 2 W.

TABLE 4.—Two partial sections of the Troutdale Formation

| Section of Troutdale measured in a gravel pit, SW¼SW¼ sec. 36, T. 8 N., R. 2 W. | Ft |
|---|---|
| Cover | |
| Sand and silt | 7 |
| Cobbly pebble conglomerate | 14 |
| Pebble conglomerate | 14 |
| Cobble conglomerate | 7 |
| Pebble conglomerate | 2 |
| Boulder cobble conglomerate | 18 |
| Contact not exposed | |

| Section of Troutdale measured along Glenwood Drive, sec. 21, T. 8 N., R. 2 W. | Ft |
|---|---|
| Cover | |
| Sand becoming silty upward | 65 |
| Pebble-cobble conglomerate | 65 |
| Contact not exposed | |

*Age and correlation.*—Hodge (1938) first considered the Troutdale to be Pleistocene in age. Later, Chaney (1944) dated the formation as lower Pliocene on the basis of fossil floral studies. Trimble (1963, p. 35), however, indicated that the flora collected by Chaney came from an older formation that underlies the Troutdale. Trimble was able to collect a flora from the Troutdale, and R. W. Brown of the U.S. Geological Survey (Trimble 1963, p. 35) suggested that it was probably early Pliocene in age. On the basis of a camel's tooth (*Auchenia*), that was found in the formation, Washburne (1914, p. 27) suggested a Pliocene age for the silt that covers the Portland Hills. This silt is considered by Lowry and Baldwin (1952) to be the upper part, or Portland Hills Silt Member, of the Troutdale Formation.

No fossils were found in the Troutdale Formation in the Kelso area. Because of lithologic similarities, the Troutdale in the Kelso area is correlated with the type section and is assigned to the Pliocene.

Contact relations.—The Troutdale Formation is a valley-fill unit in the Kelso-Cathlamet area. It unconformably overlies or is plastered up against all older formations in the area except the older Eocene volcanic rocks and the Oligocene sedimentary rocks. It, in turn, is in unconformable contact with the younger terrace deposits.

## Post-Troutdale Silty Clay

Unconformably overlying the Columbia River Basalt is a silty clay formation that is made up of two units. At some places there is a sharp contact between the units, and at other places the contact is gradational. As originally deposited, both units probably were made up mostly of silt, but deep, thorough weathering has reduced to clay practically all of the mineral grains in the lower unit. Information from core holes indicates that the thickness of the formation is fairly uniform, ranging between about 25 and 40 feet. The upper member of the formation is light brown to reddish brown in color, and the texture varies from silt to clayey silt. The lower member has been more thoroughly weathered and oxidized and is deeper red in color. Typically it is a mottled red, brown, and gray silty clay with iron-rich pisolites scattered erratically through it. Information from core holes indicates that at most places there is a zone at the base of the unit that is made up of a mixture of iron-rich pisolites in a matrix of earthy-textured gibbsite and iron oxide minerals. Differential thermal analyses made on the the lower unit indicate that, starting at the base, the gibbsite decreases upward and, usually in the space of 10 feet, disappears. These analyses also indicate that in some places the lower 3 or 4 feet of the formation may be high enough in gibbsite to be considered an ore of aluminum.

The origin of the silty clay formation is questionable. Trimble (1963, p. 4) suggests that in the Portland area it is a loess formation, as does Darton (1909, p. 11). Libbey, Lowry, and Mason (1945, p. 10), mainly on the basis of having found pebbles in the unit, propose a water-laid origin for it, as does Diller (1896, p. 485). Treasher (1942, p. 14) states that the thick silt mantle in the Portland area is of complex origin and includes residual, eolian, and fluvial deposits. In the Kelso-Cathlamet area the formation is massive, having no apparent stratification other than the separation of the two units. No pebbles were found in the clay, and the whole formation was observed to have a uniform grain size. Several samples were wet-screened through a 1/16-mm Tyler screen. The +1/16-mm material was a mixture of quartz grains and small iron oölites. About 10 to 20 percent of the quartz grains were euhedral quartzoids (so-called "beta quartz" crystals). Grubb (1963, p. 1267) found similar authigenic quartz crystals in bauxite deposits of Malaya. Frondel (1962, p. 57) also mentions that quartzoids, though typical of high-temperature quartz, have been observed frequently as "undoubted low quartz." The iron oxide-gibbsite-rich material at the base of the formation is interpreted as being reworked laterite that originally formed from the underlying basalt.

Conclusive evidence of the origin of the Post-Troutdale silty clay in the mapped area is lacking. However, the formation's massive nature and uniform grain size suggest eolian deposits. Possibly the silts were wind-transported from the flood plain of the Columbia River during a time of aridity, or during one of the early glaciations, when periodic melt-water floods covered the valley floor with silt- and clay-size material.

Age and correlation.—A lithologically similar formation in the Portland area was designated the Portland Hills Member of the Troutdale Formation by Lowry and Baldwin (1952, p. 10), who assigned it to the late Pliocene and early Pleistocene. Trimble (1963, p. 93) believes the heavy silts that overlie the bauxite deposits in Oregon are early to middle Pleistocene in age and are not necessarily related to the Troutdale Formation. In the Kelso-Cathlamet area no clear relationship between the silty clay and the Troutdale Formation has been observed. It is entirely possible that the silts represent windblown, reworked Troutdale sediments; however, it is equally possible that the deposits were blown up from the flood plain of the Columbia River after glacial floodwaters receded during the Pleistocene period. Because of this uncertainty, this unit is here assigned a post-Troutdale age.

Contact relations.—The silty clay formation unconformably overlies the Columbia River Basalt and ferruginous bauxite. This is demonstrated on the ridge between Fall Creek and Germany Creek, where part of the bauxite section was eroded away before the silty clay was deposited. Core Hole No. 2 cut a good section of gibbsite, but a little farther to the north on the ridge the silty clay is in contact with the kaolinitic transition zone between the bauxite and the basalt. At various places over the whole area the silty clay is found in contact with almost fresh basalt, altered basalt, kaolinitic bauxite, bauxite, and sedimentary rocks. There are no younger deposits directly overlying the silty clay formation.

### Terrace Deposits

River terraces are well developed along both sides of the Cowlitz River from Kelso to the north end of the area. These same terraces can be traced as far up the Cowlitz as the Mayfield Dam, in Lewis County. In the mapped area they are composed almost totally of silt, but farther up the river they become coarser grained. Results of a combination screen and pipette analysis of a 5-foot vertical channel sample taken from a roadcut in the NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 26, T. 9 N., R. 2 W., are shown in Table 5. Mineralogically, the silt is composed mostly of quartz, feldspar, biotite, and a very small percentage of ferromagnesian minerals, glass, garnet, and opaque minerals. Most of the feldspar is cloudy.

TABLE 5.—Sieve and pipette analysis of terrace silt from a roadcut in the NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 26, T. 9 N., R. 2 W.

| Grain size (mm) | Percent |
|---|---|
| 1/4 - 1/8 | 0 |
| 1/8 - 1/16 | 11.5 |
| 1/16 - 1/256 | 88.3 |
| Less than 1/ 256 | 0.2 |
| Total | 100.0 |

The terrace deposits are well exposed along U.S. Highway 99 between Rocky Point in sec. 14, T. 8 N., R. 2 W., and the north end of the area. Good exposures also occur along the West Side Highway in secs. 23, 26, 27, and 34, T. 9 N., R. 2 W.

Age and correlation.—During construction of U.S. Highway 99, a mammoth bone, identified as the posterior part of the lower jaw, was dug out of the terrace at Rocky Point. U.S. Geological Survey vertebrate paleontologists could not identify the mammoth as to species because of the lack of teeth, but they did assign it to the Pleistocene (written communication, 1953). Roberts (1958, p. 39), while working in the Castle Rock-Toledo area, acquired from a local resident a mammoth facial bone that came from a terrace believed to be contemporaneous with those in the Kelso area. It was identified as Mammuthus primigenius (Blumenback) and assigned to the Pleistocene by Jean Hough, of the U.S. Geological Survey.

## Landslides

Landslides are common in the eastern part of the area, especially around Columbia Heights and the interfluve between Clark Creek and Coal Creek. The most apparent cause for mass movements is the failure of incompetent sedimentary rocks that underlie the volcanic rocks of the Goble Volcanics and the Columbia River Basalt. The slides consist of a heterogeneous mixture of basalt, silt, sandstone, and shale.

Extensive landslide areas are in sec. 9, T. 8 N., R. 2 W.; secs. 11 and 14, T. 8 N., R. 3 W.; secs. 18, 19, and 24, T. 10 N., R. 5 W.; secs. 17 and 20, T. 10 N., R. 4 W.; and along the south slopes of Columbia Heights. Two small but well-exposed landslides are at the east end of Mount Solo in the NE. cor. sec. 25, T. 8 N., R. 3 W.

## Alluvium

Alluvium in the Cowlitz River valley is mostly sand and gravel. The gravel fragments are predominantly basaltic in composition. The alluvium along the Columbia River is sand and silt. A log from a water well in sec. 36, T. 8 N., R. 3 W., (Table 6) shows that the first gravels were encountered at 207 feet.

TABLE 6.—Log of Reynolds Metals Company water well drilled in sec. 36, T. 8 N., R. 3 W.

| Interval (feet) | Lithology |
|---|---|
| 0-1 | Sand |
| 1-28 | Blue silty clay |
| 28-71 | Sandy silt |
| 71-78 | Hard-packed sand |
| 78-99 | Sandy silt |
| 99-105 | Packed sand |
| 105-133 | Sandy silt |
| 133-138 | Packed sand |
| 138-169 | Sandy silt |
| 169-176 | Silt and clay |
| 176-181 | Sandy silt |
| 181-192 | Hard-packed sand |
| 192-197 | Hard gray silt |
| 197-207 | Hard-packed sand |
| 207-210 | Gravel |
| 210-219 | Gravel and sand |
| 219-224 | Cemented gravel |
| 224-261 | Loose gravel and sand |

## Intrusive Rocks

Plugs.—Intrusive rocks of the area are confined to small plugs and dikes. All but one are basaltic in composition; they are usually dark gray on both weathered and fresh surfaces, and typically are blocky to columnar jointed.

Three small glassy plugs are exposed within the area of the Kelso $7\frac{1}{2}$-minute quadrangle. The rocks from these intrusive bodies have similar mineralogical and physical chacteristics; they are glassy, brittle, easily crumbled, show considerable shearing, and have a well-developed spheroidal weathering habit. They are composed mostly of cloudy to clear dark glass that contains abundant microlites and mineral fragments that are chiefly plagioclase.

Two of the plugs crop out along the Kelso fault—one in the roadcut along Main Street, directly below Kelso High School, and the other in a big cut made by U.S. Highway 99 where it passes through Rocky Point. The third plug crops out along Pacific Way, directly under the Bonneville power transmission lines in sec. 13, T. 8 N., R. 3 W.

Ordway Creek intrusive.—The largest intrusive mass in the Kelso-Cathlamet area is responsible for the anomalous topographic pattern seen in parts of secs. 27, 28, 29, 32, 33, and 34, T. 10 N., R. 4 W., and secs. 3 and 4, T. 9 N., R. 4 W. The rock that makes up this body falls in the granodiorite to quartz monzonite range, containing about 50 percent potassium feldspar, 30 percent plagioclase, 15 percent quartz, and 5 percent opaques, amphibole, and biotite. A rock analysis done by the U.S. Geological Survey is shown in Table 7. The rock is light tan to light gray on both fresh and weathered surfaces, and has a blocky jointing pattern. At least two phases—early and late—of this rock are present; the late phase is finer grained and slightly darker in color than the early phase. The darker color of the late phase rock is due to an increase in opaque black and ferromagnesian minerals. Irregular clots and patches of quartz intergrown with the feldspar give the rock a pronounced granophyric texture (Fig. 7).

The optical properties of the potassium feldspar appear to be those of a feldspar intermediate between orthoclase and sanidine, and the mineral is assumed to be an orthoclase; however, more work needs to be done to confirm this. The plagioclase present is a mixture of both albite and oligoclase. Most of the feldspar crystals are cloudy, and practically all of them contain microlites that appear to be feldspar and ferromagnesian minerals. Zoning is common, as is twinning.

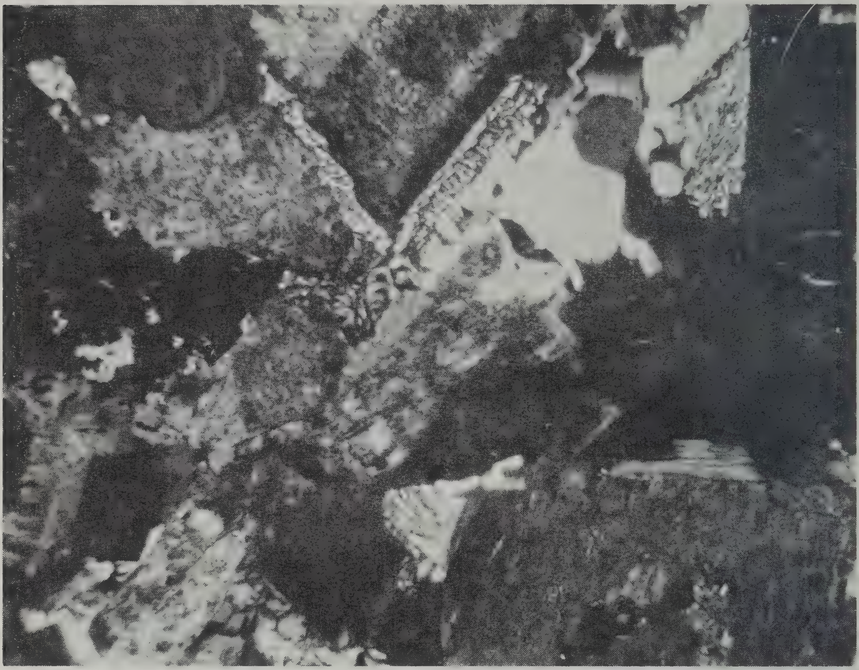


FIGURE 7.—Photomicrograph showing the granophyric texture of the Ordway Creek intrusive. Note the "wormy" appearance of quartz and the cloudy nature of feldspars. (X 50—crossed nicols.)

In some crystals there are fairly clear cores surrounded by extremely cloudy rims, and in other crystals the reverse is true. Many of the feldspars are ragged and appear to have undergone severe deuteric corrosion.

The quartz is interstitial to granular and commonly is found as wormy intergrowths with the feldspars. Quartz is most abundant in the coarser grained material and diminishes to less than 10 percent in the finer grained material.

Opaque minerals are most abundant in the fine-grained material and along the chilled contacts. Ferromagnesian minerals occur in lesser amounts.

The contact relations of this intrusive rock with the surrounding rocks have not been observed, so its age and method of emplacement are not known. Outcrops can best be seen along the Ordway Creek Road in secs. 28 and 33, T. 10 N., R. 4 W.

TABLE 7.—Chemical analysis of the Ordway Creek intrusive[1]

| | Percent |
|---|---|
| $SiO_2$ | 67.1 |
| $Al_2O_3$ | 15.0 |
| $Fe_2O_3$ | 3.7 |
| FeO | 1.2 |
| MgO | 0.66 |
| CaO | 0.81 |
| $Na_2O$ | 4.4 |
| $K_2O$ | 4.8 |
| $H_2O-$ | 0.57 |
| $H_2O+$ | 0.63 |
| $TiO_2$ | 0.65 |
| $P_2O_5$ | 0.12 |
| MnO | 0.09 |
| $CO_2$ | Less than 0.05 |
| Total | 100.00 |

[1] Analysis by Paul Elmore, Sam Botts, Gillison Chloe, Lowell Artis, and H. Smith, U.S. Geological Survey.

Dikes.—Dikes in the Kelso-Cathlamet area that were examined are all basaltic in composition. They generally have northwest to west trends, are fairly narrow in width, and usually cannot be traced more than a few tens of feet. Most of them seem to have more affinities with the Goble flows than with the Columbia River Basalt.

There are several dikes cropping out around the north end of the monzonite body that are very different from most of the other dikes in the Kelso-Cathlamet area. One contains labradorite phenocrysts as much as 2 cm long in a groundmass of fine-grained labradorite and augite. Many of these large crystals are bent and sheared, and all of them contain inclusions and microlites of plagioclase and augite.

The augite occurs as little clusters of rounded grains. Opaque minerals are equidimensional and very abundant. Another dike that occurs in this same area is characterized by large crystals of olivine (up to 2 mm) and pigeonite (up to 8 mm). Most of the olivine has been replaced by either antigorite or iddingsite, but the pigeonite crystals are fresh and relatively unaltered. The groundmass is composed of about equal parts of fine laths of plagioclase, in the range between calcic andesine and sodic labradorite, and granules of augite.

## Structure

### Folds

The Tertiary strata of the Kelso-Cathlamet area have been folded into several major anticlines and synclines that are parallel with the northwest-southeast regional structural trend. Smaller flexures superimposed upon the limbs of the major folds vary in trend from east-west to north-south. Dips of the strata range from flat lying to 46°, the average dip being somewhere between 15° and 20°.

Willapa Hills anticline.—The major structure in the area is a broad anticline, the axis of which more or less forms the north boundary of the reconnaissance map. Strata of Miocene, Oligocene, and Eocene age are exposed along its southern flank. The axis of the fold strikes northwest toward the Willapa Hills anticline of Henriksen (1956, p. 96) and is considered to be a continuation of that flexure. To the southeast it is obliterated by a series of smaller north-south-trending folds.

The anticline is best observed along the Elochoman River between secs. 1 and 24, T. 10 N., R. 5 W., where a reversal of dips occurs. From north to south in this area the river cuts through north-dipping Cowlitz Formation, then through south-dipping Cowlitz Formation, Goble Volcanics, Oligocene sedimentary rocks, and Columbia River Basalt, in that order.

Bradley Heights syncline.—Paralleling the south branch of the Willapa Hills anticline on the south is the Bradley Heights syncline. This is a broad, fairly flat fold, which is expressed at the surface by rocks of Miocene age. Southward in Oregon, well-developed dip slopes held up by the Columbia River Basalt have developed on the south limb of the syncline. The axis of the flexure enters the area near Family Camp in the Elochoman River valley, trends southeast across Bradley Heights, and connects with the large syncline shown by Peck (1961) on the Oregon side of the Columbia River.

Columbia Heights anticline. — The Columbia Heights anticline is the most prominent flexure in the vicinity of Kelso. Its axis trends about N. 30° W. to the south end of Columbia Heights, near the NE. cor. sec. 27, T. 8 N., R. 2 W., where it plunges beneath the alluvium at West Kelso. Northwestward, the fold dies out in the Delameter Valley. The fold is flanked on the west, south, and east by volcanic rocks of the volcanic member of the Cowlitz Formation. Columbia River Basalt surrounded by Cowlitz sedimentary rocks crops out along the axis of the structure. This anomalous condition is the result of two periods of deformation. The first was post-Goble, followed by the outpouring of the Columbia River lavas that covered the fold. The second phase was post-Columbia River Basalt. Subsequent erosion has cut away most of the basalt except for the area along the axis of the fold. Weaver (1916a, Plate III) mapped the Columbia Heights anticline as a syncline; his conclusions were undoubtedly based on the anomalous distribution of formations.

Hazel Dell syncline. — The Hazel Dell syncline parallels the Columbia Heights anticline on the northeast. It enters the north part of the area in sec. 20, T. 9 N., R. 2 W., and trends southeast out of the area in sec. 13, T. 8 N., R. 2 W. The volcanic member of the Cowlitz Formation crops out on the west, south, and east sides of the fold; Cowlitz sedimentary rocks crop out along the axis.

Minor folds. — Minor folds and flexures are numerous in the area, and their orientations are various. Generally, however, they trend east-west. The axes of the folds are relatively short; none of them are much more than a mile in length, and most appear to be much shorter. The size and nature of these smaller folds can best be seen along Coal Creek, where outcrops are almost continuous along the stream channel.

## Faults

The overall fault trend in the area, with few exceptions, parallels the major fold trends. Faulting appears to have played a minor role in the structural development of the area; however, this may be a misconception caused by the difficulty in recognizing and mapping fractures. Because of thick overburden, scarcity of outcrops, and lack of marker beds, recognition of faults is difficult at best. Because of this there may be many faults that are not mapped and that might add more structural complexity to the area. The few faults mapped appear to be high angle, and evidence for relative movement of the fault blocks is meager or lacking.

Kelso fault. — The Kelso fault is a large north-trending structure that extends from Kelso northward through the east side of Rocky Point. Throughout the Kelso area, basalt on the west side of the fault is in juxtaposition with sedimentary rocks on the east side of the structure. There is no evidence as to the relative movement of the walls or the inclination of the fault plane. Glassy volcanic plugs that have come up along the fault are exposed in the roadcut on Main Street below Kelso High School and in the highway cut at Rocky Point.

Harmony Creek faults. — The Harmony Creek faults are a group of three echelon faults that have an apparent slight rotational movement. The eastern end of the easternmost fault is near the center of sec. 10, T. 8 N., R. 3 W., just below the falls in Harmony Creek (previously called Mosquito Creek — U.S. Board of Geographic Names, 1959, p. 43). Here the southwest block has moved up with respect to the northeast block. A massive gray sandstone unit of the Cowlitz Formation has been pushed up against the dense, hard black columnar Columbia River Basalt. At several places in the creek bottom below the falls a gouge zone crops out between the two formations. Displacement along the fault in this area appears to be about 50 to 75 feet, but there is no obvious surface evidence to indicate the attitude of the fault plane.

To the northwest the trace of the faults is expressed by a linear topographic depression along which Harmony Creek flows. At the northwest end of the westernmost fault the relative movement along the fault plane is opposite to what it was at the southeast end. Flat-lying ferruginous bauxite deposits that developed in the Columbia River Basalt and that once were continuous are displaced about 150 feet, the southwest block having been dropped down.

Abernathy Creek fault. — The largest, most pronounced structural alignment in the Kelso-Cathlamet area, the Abernathy Creek fault, is along Abernathy Creek between sec. 32, T. 10 N., R. 4 W., and sec. 26, T. 9 N., R. 4 W. If this lineation is projected across the Columbia River into Oregon, it lines up with the straight valley of Green Creek between secs. 20 and 33, T. 8 N., R. 3 W. Neither lineation (Abernathy Creek in Washington or Green Creek in Oregon) has previously been shown to be a fault; however, inasmuch as they are in Columbia River Basalt, stratigraphic displacement may be hard to detect. Perhaps the most logical explanation is that the lineation represents a large tear fault. Many of the critera listed by de Sitter (1956, p. 193-194) as evidence for this type of fault are present. To name a few: the topographic expression is remarkably rectilinear, the angle between the fault and the main fold axis is less than 45°, and the topographic expression indicates that the fault plane is vertical or near vertical. The possibility of a major pre-Columbia River Basalt fault in the Eocene and Oligocene rocks should be considered. The major lineation in the basalt may have been caused by a later, minor movement along such a fault.

Other faults. — There are several small faults in the area that warrant description because of their stratigraphic and physiographic significance.

Evidence for two small faults that cut the Columbia River Basalt and the Cowlitz Formation can be seen in sec. 7, T. 8 N., R. 2 W. These are northwest-trending fractures, the block between which has been upthrown, leaving Cowlitz up against Columbia River Basalt. Displacement along the northeast fault is about 75 feet, and along the southwest one about 150 feet, based on the elevation of the contact between the two formations on each side of the faults. These two faults are expressed topographically by the two steep ravines in the east valley wall. Immediately south of and parallel to these faults are two more small straight steep ravines that are also thought to be the surface expression of two small faults.

At the northwest corner of the Kelso quadrangle, in secs. 29 and 30, T. 9 N., R. 2 W., is a fault that has a strike normal to the regional trend, that is, northeast, and that truncates the volcanic member of the Cowlitz Formation. Sedimentary rocks on the northwest side of the fault are in contact with volcanic rocks on the southeast side.

A small fault trends parallel to the Harmony Creek fault and extends from about the NE. cor. sec. 35, T. 9 N., R. 4 W., to the Columbia River in the SE. cor. sec. 8, T. 8 N., R. 3 W. Evidence for this fault is the lowering of the once continuous ferruginous bauxite deposits by about 300 feet on the southwest side. This fault may also truncate the volcanic member of the Cowlitz Formation in the SE$\frac{1}{4}$ sec. 8, T. 8 N., R. 3 W. Thick underbrush and cover prevents walking out the Eocene unit to see if it actually has been brought up in fault contact with the Columbia River Basalt. There is no evidence to suggest whether the fault is normal or reverse.

A small fault striking about N. 40° W. is exposed in a roadcut along Pacific Way near the E. $\frac{1}{4}$ cor. sec. 13, T. 8 N., R. 3 W. The fault plane dips approximately 60° to the northeast, and slickensides indicate that the last movement was in the direction of the dip. The southwest block of the fault is a light-gray to buff sandstone that strikes N. 10° W. and dips 6° SW. The northeast block is light-gray to brownish siltstone that strikes N. 5° W. and dips 8° NE. There is no evidence as to the relative movement of the fault blocks.

A small N. 60° W.-striking fault cuts Goble Volcanics and the Cowlitz Formation along Germany Creek. It cuts across sec. 1, T. 9 N., R. 4 W., and part of sec. 7, T. 9 N., R. 3 W. The upthrown block, which is on the southwest side of the fault, has brought up Cowlitz sedimentary rocks into juxtapositon with Goble volcanic rocks. Topographic evidence indicates that the fault plane is vertical. A small creek has cut a straight course along the fault trace in the west wall of the Germany Creek valley.

The plane of a N. 40° W.-striking, 40° NE.-dipping fault is exposed in a roadcut in sec. 27, T. 10 N., R. 4 W. On the basis of the alignment of stream courses in the southern part of sec. 35, T. 10 N., R. 4 W., and in secs. 2, 11, and 12, T. 9 N., R. 4 W., with the exposed trace, it is believed that this fault may extend as far southeast as Germany Creek. Its northwestern extension and its relative movement are not known.

What is shown on Figure 23 (in pocket) as a normal unconformable contact between the Goble Volcanics and the Columbia River Basalt may in reality be a fault contact. Evidences that suggest faulting are the lineations developed along the contact and the failure of the contact to conform to the topography.

## HISTORICAL GEOLOGY

The earliest geologic event recorded in the rocks of the Kelso-Cathlamet area was the outpouring during early through middle Eocene time of the pre-Cowlitz basalts that are exposed in the core of the Willapa Hills anticline in sec. 7, T. 10 N., R. 4 W. According to Henriksen (1956, p. 23 and 110), these flows piled up a thickness of at least 8,000 feet in a fairly rapidly subsiding eugeosynclinal trough. The pre-Cowlitz volcanics in the mapped area appear to be sub-aerial in origin; however, both Henriksen (1956, p. 110) and Snavely and Wagner (1963, p. 1) indicate that the volcanic centers were along a low coastal plain or were submarine, and that the lava flowed out into a shallow sea and occasionally built up volcanic islands.

Following the pre-Cowlitz volcanism, deposition of the Cowlitz Formation began. In the eastern part of the area, coarse near-shore sediments were deposited, while at the same time but farther west, finer grained offshore marine beds were being laid down. The depositional basin continued to subside fairly rapidly throughout late Eocene time, when, according to Weaver (1916a, p. 91) and Henriksen (1956, p. 35), about 8,000 feet of predominantly sand and silt were deposited. Only about 1,800 feet of this section is exposed in the mapped area. When minor fluctuations of the sea level occurred in the area during the deposition of the Cowlitz

Formation, several large near-sea-level, abundantly vegetated swamps developed along the coast. The vegetal material that accumulated in the swamps was eventually covered by sediments and altered to coal. Volcanism apparently was continuously active east of the region, and occasionally lavas from nearby volcanos flowed into the area and became interbedded with the sediments.

Near the end of Eocene time, regional volcanism became increasingly active and several volcanos developed on the land bordering the seacoast. From these volcanos the flows, breccia, and tuff beds constituting the Goble Volcanics accumulated to a thickness of over 5,000 feet (Wilkinson, Lowry, and Baldwin, 1946, p. 5). As the lavas flowed into the area from the east and southeast, they built up the landmass faster than the rate of subsidence and erosion and, as a result, pushed the seashore to the northwest. Because of this, most of the area was probably emergent during latest Eocene and earliest Oligocene time. As the Goble volcanic activity began to diminish, the sea encroached eastward and lower Oligocene sediments were deposited between flows.

During the latter part of Oligocene time the area was uplifted, folded, and faulted. By early to middle Miocene time, when the Columbia River lavas were extruded, erosion had reduced the area nearly to base level. Minor fluctuations of sea level during this time are indicated by the beach sands that are intercalated with the basalt in the central and western part of the area.

During late Miocene and earliest Pliocene times the area was subjected to uplift again, and the Columbia River cut its present course through the region. It was probably during this time that laterization of the Columbia River Basalt began. The area was depressed slightly during early Pliocene, and the valley-fill sediments of the Troutdale Formation were deposited by the Columbia River, apparently completely choking its valley with clastic debris.

A period of orogeny took place in the early Pleistocene, when the area was generally elevated and the Coast Range was folded and uplifted. Folding was intensified along the older, pre-existing fold axes, and the Columbia River eroded most of the Troutdale Formation out of the valley, leaving scattered patches of quartzite pebble-rich gravels plastered against the valley walls.

During the late Pleistocene, terrace deposits were laid down adjacent to the Cowlitz and Coweman Rivers, and ice-rafted granitic glacial erratics were dropped along the lower slopes (none above 100 feet in elevation) of the Columbia River valley. Apparently, during this time of glacial retreat in the northern part of the state, the sea level rose or the landmass subsided slightly, causing the tributaries of the Columbia to fill their valleys with terrace deposits, the tops of which were near sea level in elevation at that time. Subsequent uplift and erosion have left remnants of the terraces along the valley walls at about 100 to 180 feet in elevation.

## ECONOMIC GEOLOGY

### Coal

Coal beds in the Cowlitz Formation crop out along Coal Creek and in the valleys of some of the smaller streams in the area. Only two mines were opened in the area, one along Coal Creek and the other near Rocky Point. Neither mine has been operated during the past 40 or 50 years; consequently there is no current information on them, and because of the dense vegetation and thick soil cover it is impossible to trace the coal beds without the aid of core holes.

### Anchor Mine

The Anchor mine, in the SW¼ sec. 13 and the SE¼ sec. 14, T. 8 N., R. 2 W., was first opened in 1891 by the Anchor Coal and Development Company, of San Francisco. The plan was to transport the coal by rail from the mine to the Cowlitz River, a distance of about three-quarters of a mile, then by barge to Portland, Oregon. Culver (1919, p. 48) states that two entries were made on the coal seam, both in sec. 13. Newer maps show that the west portal is actually in sec. 14. The east portal was made in thin-bedded to laminated micaceous sandstone and lignitic shale striking N. 60° W. and dipping 10° SW. The tunnel has caved, and the only evidence left that indicates a mining operation there is part of the old dump. About 500 feet to the west and at creek level, the second tunnel was cut in a section of medium-bedded, buff-colored, fine-grained sandstone and laminations of lignitic shale striking N. 70° W. and dipping 30° SW. The portal is still open, but the workings are full of water.

Landes (1902, p. 64) reported that two seams were being worked, one about 4 feet thick and the other about 5 feet thick. Culver (1919, Fig. 3b, p. 49) measured a section in the west portal that is shown in Figure 8.

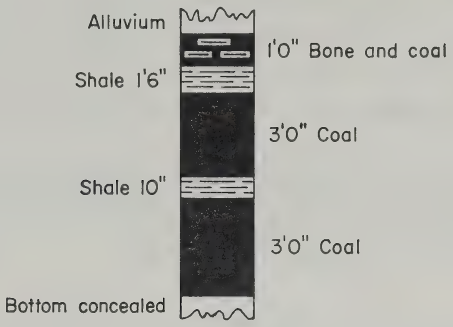

Alluvium
1'0" Bone and coal
Shale 1'6"
3'0" Coal
Shale 10"
3'0" Coal
Bottom concealed

FIGURE 8.—Coal section at the west portal of the Anchor mine. (from Culver, 1919, p. 49)

Culver reports that the mine operated from 1891 to 1897, during which time 4,600 tons of coal was mined. Beikman, Gower, and Dana (1961, p. 105) estimate that there are 3.46 million tons of inferred reserves in the coal beds that the Anchor company operated. They also estimate 2.29 million tons of inferred reserves in a bed that is in secs. 1 and 12, T. 8 N., R. 2 W., and secs. 6 and 7, T. 8 N., R. 1 W.; the writer was unable to find this bed.

## Coal Creek Mine

The Coal Creek mine was opened in 1901 by the Coal Creek Development Company, of The Dalles, Oregon (Landes, 1902, p. 64). It is in sec. 27, T. 9 N., R. 3 W., about 8 miles west of Kelso. The plan was to build a standard-gauge

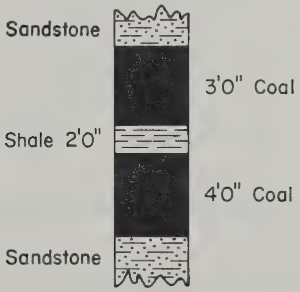

Sandstone
3'0" Coal
Shale 2'0"
4'0" Coal
Sandstone

FIGURE 9.—Coal section at the Coal Creek mine. (from Landes and Ruddy, 1903, p. 256)

railroad from the mine to the Columbia River (a distance of 4 miles), where the coal would be loaded into barges and shipped to Portland, Oregon. At the mine, Landes and Ruddy (1903, p. 256) measured the coal section shown in Figure 9. Diller (1905, p. 411) measured the coal section in the mine and reported:

> The coal bed is 6 to 7 feet in thickness, with two small partings of sand. The top bench has 12 to 18 inches of bony coal, the middle bench 2½ feet of better quality, and the lower bench 18 inches of coal, in part good. The coal is overlain by soft sandstone.

Typically, the coal lost its luster and slaked when exposed to air. Two samples taken by Diller (1905, p. 412), one from the middle (No. 6760) and one from the lower (No. 6761) bench, were tested by W. T. Schaller, of the U.S. Geological Survey laboratory, with the results shown in Table 8.

TABLE 8.—Analyses of coal from the Coal Creek mine. (from Diller, 1905, p. 412)

| | No. 6760 | | No. 6761 |
|---|---|---|---|
| | Finely ground | Coarsely ground | Finely ground |
| Moisture ........... | 15.24 | 22.22 | 16.26 |
| Volatile combustible matter ............ | 36.28 | 33.30 | 36.33 |
| Fixed carbon ........ | 29.54 | 27.11 | 30.05 |
| Ash ................ | 18.94 | 17.37 | 17.36 |
| | 100.00 | 100.00 | 100.00 |
| Sulfur .............. | 4.39 | 4.03 | 4.61 |
| Color of ash ......... | Light red-brown; noncoking. | | |

Diller (1905, p. 412) reported that the beds near the mine strike northwest and dip about 15° to the southwest.

There is no available record of the Coal Creek mine's production; however, that it did produce some coal is evident by Diller's (1905, p. 411) statement:

> An incline follows the coal downward at an angle of 5° to 18° for 400 feet. Drifts run a short distance both ways . . . and about 15 tons of coal were already in the bunkers.

Beikman, Gower, and Dana (1961, p. 105) estimate that there are 2.13 million tons of inferred reserves in the Coal Creek mine beds. There are other coal seams exposed along the channel of Coal Creek, particularly in sec. 11, T. 8 N., R. 3 W. They are associated with carbonaceous shales and sandstones, and are very impure.

### Oil and Gas

Several oil companies have done oil and gas exploration work in the Kelso-Cathlamet area. The Texas Company drilled three core holes along Clark Creek in 1943, but no oil and gas tests have been made in the area. The only observable structures in the area that appear to be suitable for the accumulation of oil and gas are the Willapa Hills anticline and the Columbia Heights anticline. There may be many stratigraphic traps, however.

The brackish-water, near-shore sandstone beds of the Cowlitz Formation could well serve as reservoir rocks, and the marine siltstones and claystones in the western part of the area might serve as source rocks.

### Sand, Gravel, and Crushed Rock

The conglomerate phase of the Troutdale Formation is used extensively for sand and gravel in the area. There are several pits that intermittently produce crushed and pit-run material. Gravel pits are situated in the SW. cor. sec. 36, T. 8 N., R. 2 W.; the SE$\frac{1}{4}$ sec. 23, T. 8 N., R. 2 W.; and the SW$\frac{1}{4}$ sec. 21, T. 8 N., R. 2 W. The material from these pits does not appear to be suitable for concrete aggregate because of the weathering rind that exists on most of the basalt fragments.

The irregularly jointed flows of the Columbia River Basalt and some of the Goble flows are worked for ornamental stone and crushed rock. The columnar-jointed rock of the Columbia River Basalt is quarried as needed for riprap and jetty stone. Rock pits are situated along the south side of Mount Solo; along U.S. Highway 99 near the W. $\frac{1}{4}$ cor. sec. 25, T. 9 N., R. 2 W.; along U.S. Highway 830 in sec. 15, T. 8 N., R. 3 W.; at Alder Bluff in sec. 8, T. 8 N., R. 3 W.; and at the mouth of Mill Creek in sec. 9, T. 8 N., R. 4 W.

## Peat

There are several peat bogs on the alluvial flats west of Longview. None of them are being worked commercially, nor is there any information as to their depth. The surface of one bog is under cultivation for growing mint.

## Ferruginous Bauxite

### Location and Previous Investigations

The known deposits of ferruginous bauxite[1] ores[2] in Washington are limited to the Kelso-Cathlamet area. The deposits lie along several of the relatively flat-topped ridges and on the uplands extending northward from the Columbia River toward the highlands (Fig. 23, in pocket). The laterite that makes up the deposits consists of a mixture of aluminum and iron oxide minerals together with varying amounts of both combined and free silica, and other impurities.

The ferruginous bauxite deposits of southwest Washington were probably first discovered in 1946 by the Alcoa Mining Company, which had been working on similar deposits in northwest Oregon (Libbey, Lowry, and Mason, 1945; Libbey, Lowry, and Mason, 1946; Allen, 1948; and Corcoran and Libbey, 1956). Since that time the Harvey Aluminum Company and the Reynolds Metals Company have also carried out drilling programs in Cowlitz and Wahkiakum Counties. In conjunction with their work, both Alcoa and Reynolds acquired several large land blocks through mineral leases and outright purchases.

During the fall of 1961 the Division of Mines and Geology carried out a modest drilling program to get bauxite samples for analysis and study and to help in trying to determine the character, origin, and distribution of the deposits. Ten core holes were drilled (Fig. 23, in pocket) along several ridge tops between Coal Creek and the Elochoman River. Differential thermal analyses were made on samples taken from each core, and the material that gave a good gibbsite thermal peak was assayed for $Al_2O_3$, $Fe_2O_3$, $TiO_2$, $SiO_2$, and loss on ignition.

---

[1] In this report the terms "ferruginous bauxite" and "laterite" are used interchangeably.

[2] The term "ore" is used herein for the sake of convenience; it has not been proven that the ferruginous bauxite, to which it refers, can be mined at a profit.

## Age of Laterization

The laterization process probably started soon after the final outpouring of Columbia River Basalt and continued at least until the laterite was covered by the overlying silt. When the final flows of the Columbia River lava were poured out, the area was practically at sea level, as indicated by the interbedded beach sands that occur between basalt flows in many places. The land surface at that time was probably flat, and the drainage was poor. As the region was epeirogenically elevated (probably not more than 1,000 feet), dissection of the lava plain began and the good drainage system that is necessary for the development of bauxite deposits was established.

The presence of the early Pliocene valley-fill Troutdale Formation high on the walls of the Columbia River valley indicates that the Columbia River had cut a channel previous to early Pliocene time and that the uplift took place between middle Miocene (the age of the Columbia River Basalt) and the cutting of the channel in late Miocene or earliest Pliocene time. This establishes the age of laterization as beginning no earlier than in the late Miocene. Trimble (1963, p. 92-93) suggests that laterization continued until the bauxite was covered by silt overburden some time during early to middle Pleistocene. Libbey, Lowry, and Mason (1945, p. 14) believe that laterization was stopped by folding and erosion during early Pliocene and that the silt was deposited during late Pliocene or early Pleistocene time. Evidence in the Kelso-Cathlamet area tends to support the theories of Trimble (1963) and Libbey, Lowry, and Mason (1945) as to the events that stopped the laterization. The angular unconformity between the silt and the bauxite indicates that folding and erosion had commenced before the deposition of the silt. The continuity of the silt deposits over the rolling upland part of the area indicates that the faulting that displaced the bauxite deposits also preceded deposition of the silt. Laterization probably continued through the period of folding and erosion right up until the deposition of the silt. In fact, considering the abundant rainfall, mild climate, and good drainage in the area at the present time, it is possible that laterite is forming today.

## Description of the Deposits

The laterite in the Kelso-Cathlamet area is similar to that which occurs across the Columbia River, in Oregon. In the mapped area the ferruginous bauxite occurs as a series of deposits that overlie the Columbia River Basalt along many of the broad flat-topped ridges and uplands that border the Columbia River (Fig. 10). Originally, the deposits were more extensive than they are today, but the accelerated erosion that accompanied postformational folding and faulting has diminished their size.

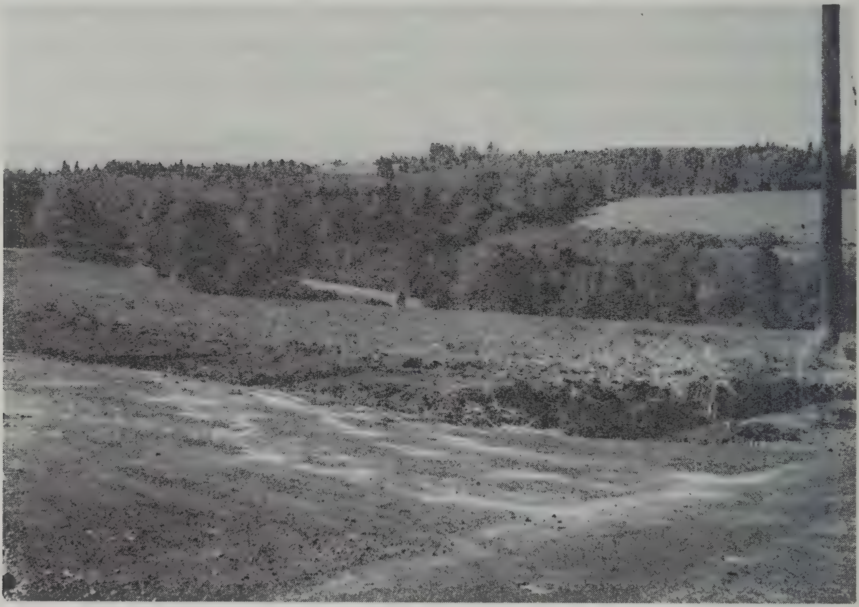


FIGURE 10.—Stella Heights (looking southwest), showing the broad flat-topped uplands on which bauxite occurs.

In preparing an estimate of bauxite ore tonnage for the Kelso-Cathlamet area, it was necessary to make some basic assumptions in an almost arbitrary manner. The total area that is underlain by bauxite in this region is not accurately known, but by measuring the area estimated to be underlain by bauxite, a figure of 2,200 acres was arrived at. The area included in this estimate was outlined by analysis of the topography, through information gathered from aluminum companies, from aluminum company land ownership and leases, outcrops of laterite, and a few core holes. Assuming that these 2,200 acres are underlain by an average of 10 feet of ferruginous bauxite that contains less that 15 percent silica, there are about 70 million tons of ore present.[1] The 15-percent figure for silica was arbitrarily chosen as the cutoff point. The 10-foot thickness was arrived at by examining analyses provided by aluminum companies and analyses from State core holes, and by talking with people who are familiar with the deposits. Actually, 10 feet is probably a conservative estimate.

One of the important problems that must be taken into account in any economic consideration of the bauxite is: How much overburden must be removed to get at the ore? Evidence from the core holes drilled by the State, information supplied by aluminum companies, and conversations with people who are familiar with deposits, all indicate that the overburden is from 1 foot to 30 feet in thickness. No attempt has been made to estimate the cubic yards to be removed.

The outline of the deposits apparently is controlled to a large extent by the topography. Most of the broad interfluves between Coal Creek and the Elochoman River are capped by laterite. The deposits are almost sheetlike in shape, covering the ridge tops and draping a short distance down the adjacent slopes. The laterite has been covered by silt deposits that effectively mask any irregularities in its surface; however, drilling in the area indicated that the laterite surface is fairly uniform. The base of the ore probably is fairly regular also. Variations in jointing and (or) mineralogy in the parent rock may have influenced the depth of laterization, but resulting irregularities in the base of the ore probably are small.

Three basic ore types occur in the bauxite deposits of the Kelso-Cathlamet area. These same three types—earthy, nodular, and pisolitic (for convenience, the term "pisolite" is used herein to include both oölites and pisolites)—were described by Libbey, Lowry, and Mason (1945 and 1946) in the Oregon deposits. In the Kelso-Cathlamet area the color of the ferruginous bauxite varies from mustard yellow through brown and various tones of red, red being the most common. The nodules (Fig. 11) from core holes are always yellowish, but those found in surface outcrops are reddish. Pisolites are dark brown to black on fresh surfaces and weather to dark reddish brown. They also show varying degrees of magnetic susceptibility, some being attracted to a magnet only slightly, whereas others are very strongly attracted.

The nodular ore is a mixture of hard, gibbsite-rich nodules and soft earthy material. Thin sections of nodules viewed by plane polarized light show that the original intersertal igneous texture of the parent rock is preserved (Fig. 12).

---

[1] The U.S. Bureau of Mines (Robert A. Miller, written communication, Jan. 19, 1966), as a result of its work on laterite in Oregon, has concluded that there will be an ore-waste ratio of about .57.

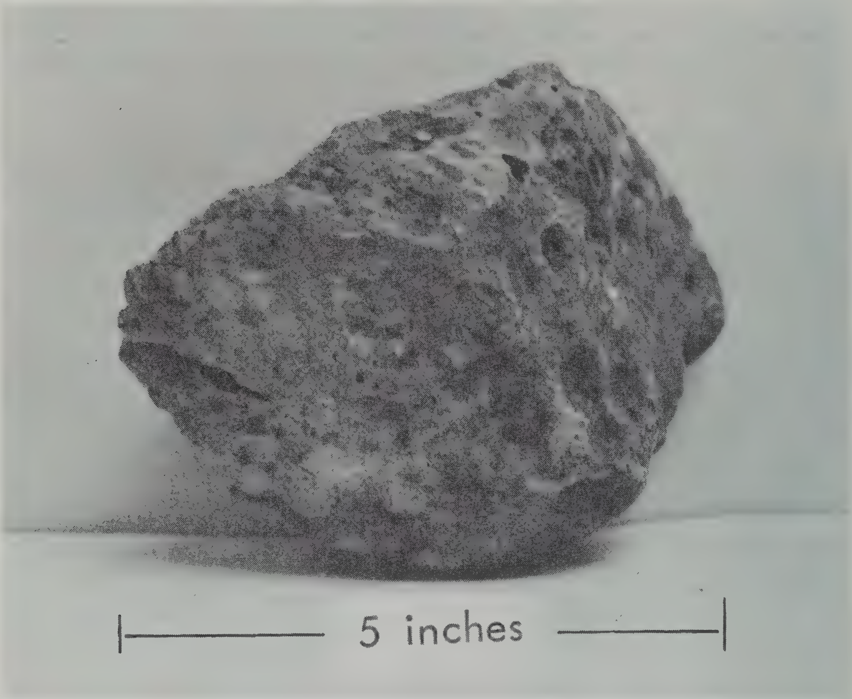


FIGURE 11.—Typical bauxite nodule that has weathered out of the ore zone. Note the pitted or vuggy appearance, which is also typical.

The original plagioclase crystals were mostly subhedral to euhedral laths, but there were also a few tabular forms. The groundmass or matrix is mottled and cloudy, and reddish brown in color. It appears to have been made up of granules, probably of augite and glass, before alteration (see description of the Columbia River Basalt, p. 37). The opaque minerals are all black and occur in acicular blades, dendritic masses, and irregular equidimensional grains. Examined under crossed nicols, the texture of the nodules is seen to be granular (Fig. 13). The plagioclase crystals have been replaced by gray, finely granular gibbsite, and the augite grains by a mixture of gibbsite and reddish iron oxide. Some fractures extending through the nodules have been filled with gray crystalline gibbsite, and others with a creamy red material that has a scalloped or colloform structure. The earthy material appears to be the same in both the earthy and the mixed nodular and earthy varieties of ore. The texture is granular, and there are easily recog-

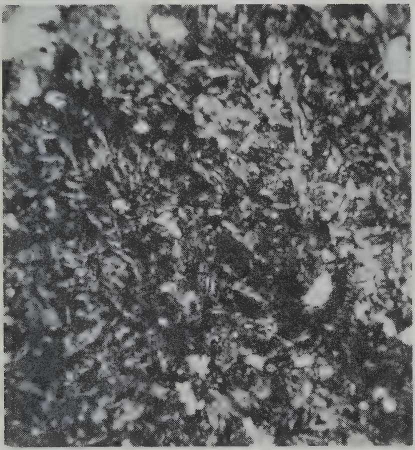


FIGURE 12. — Photomicrograph of bauxite nodule, using plane light, showing relict igneous texture. (X 50.)

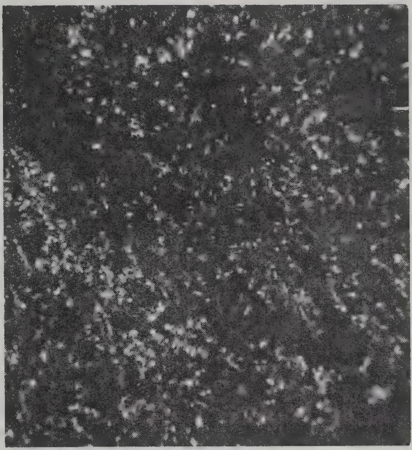


FIGURE 13. — Photomicrograph of same section as in Figure 12, using crossed nicols. Relict textures are no longer visible. (X 50.)

nized grains of clear gibbsite in an extremely fine grained matrix. The matrix is cloudy and has areas of deep red, creamy-textured material that often has a colloform structure along fractures.

Examination of a thin section of pisolitic ore (Fig. 14) taken from an old well on the J. R. Williamson property (SW¼NE¼ sec. 1, T. 8 N., R. 4 W.) showed that the bauxite was made up of larger pisolites imbedded in a matrix of smaller pisolites and fine-grained granular material. The fine-grained granular part of the matrix is similar to the earthy variety of the ore. There were no relict igneous textures present in any part of the pisolitic ore that was examined. Most of the pisolites have a granular texture, and many are grouped together in reniform masses. The smallest pisolites are less than 0.01 mm in diameter, and the largest are more than 1 cm. Most of them, however, fall in the 0.5 mm to 5 mm size range.

The pisolites vary in composition. Some are fairly homogeneous, being made up mostly of a light-brown mixture of isotropic cliachite(?) and limonite and a scattering of clear grains of gibbsite. Other pisolites have a dark opaque core surrounded by a rim of light material similar to that described above in the homogeneous pisolites. Some of the larger pisolites are aggregates of tiny pisolites and homogeneous granular material.

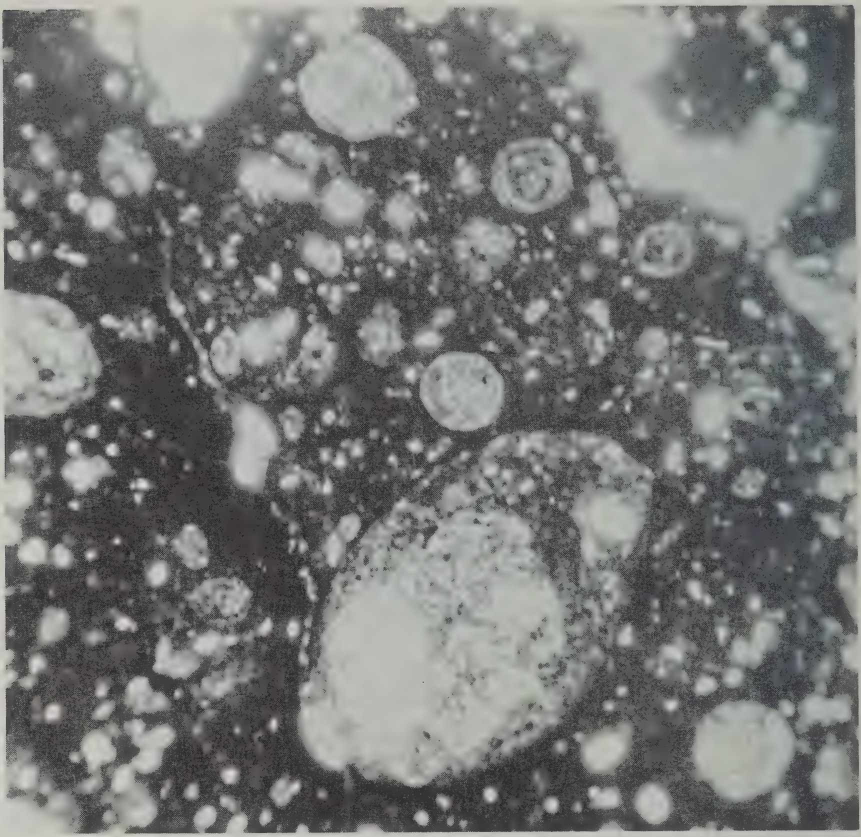


FIGURE 14.—Photomicrograph of pisolitic bauxite. Light areas are made up of cliachite(?) and gibbsite. Dark areas contain a considerable amount of limonite. Sample from J. R. Williamson property, sec. 1, T. 8 N., R. 4 W. (X 50—plane light.)

Pisolites from the base of the clay formation that overlies the bauxite are very different from the pisolites that occur in the bauxite. They are composed of opaque steel-gray and almost opaque rust-red-colored iron minerals. Entombed in the pisolites are abundant quartz grains that are euhedral to subhedral in shape. These are terminated hexagonal dipyramids. Even though these crystals appear to be typical of high-temperature quartz, they are thought to be authigenic here (see page 46). Rust-red material having a granular texture and colloform structure is common. It contains little cavities and fractures that are lined with clear gray gibbsite crystals. Using a metallographic microscope, the opaque gray mineral was tentatively identified as magnetite. It has a colloform structure and forms an irregular core in the pisolites. It has inclusions of rust-red material and a lighter gray reaction rim surrounding it.

## Mineralogy of the Bauxite

Several minerals were recognized in the bauxite, the most abundant being gibbsite. Petrographically, gibbsite and halloysite were tentatively identified and quartz was positively identified. A questionable identification of cliachite was also made petrographically. Magnetite was tentatively identified by polished-section work. Gibbsite and kaolinite-type clay were identified by differential thermal analysis (Fig. 15). A tentative diaspore or boehmite identification (George Carter, Ceramic Engineer, U.S. Bureau of Mines, Seattle, written communication, 1963) was also made by differential thermal analysis. Three samples, one with a high silica content, CH No. 2, 24-27 ft (16.01 percent); one with a medium silica content, CH No. 2, 33-36 ft (7.10 percent); and one with a low silica content, CH No. 7, 30-33 ft (1.22 percent), were sent to the U.S. Bureau of Mines in Seattle for differential thermal and X-ray analyses. Carter, (written communication, 1963), reported the following:

> Differential thermal analysis (DTA): Gibbsite was the only major component detected in each of the samples. Samples C-2162 (CH No. 2, 24-27 ft) and C-2164 (CH No. 7, 30-33 ft) contained only trace amounts of kaolinite-type clay. Sample C-2163 (CH no. 2, 33-36 ft) contained a very small amount of kaolinite-type clay, about two or three times as much as samples C-2162 (CH No. 2, 24-27 ft) and C-2164 (CH No. 7, 30-33 ft).
>
> X-ray diffraction: Only three minerals—gibbsite, goethite, and quartz—could be positively identified from the X-ray diffraction tracings of samples C-2162 (CH No. 2, 24-27 ft), C-2163 (CH No. 2, 33-36 ft), and C-2164 (CH No. 7, 30-33 ft), although there were several peaks on each pattern not attributable to these minerals. Gibbsite, the major component of the mineral suite in each of the three samples, appeared from peak height intensity to be present in varying amounts in the three samples. The amount was greatest in sample C-2163 (CH No. 2, 33-36 ft), decreasing slightly in sample C-2162 (CH No. 2, 24-27 ft), and decreasing still more in sample C-2164 (CH No. 7, 30-33 ft). Peak height intensity is not an absolute quantitative measurement, because it is greatly influenced by preferred orientation and the degree of crystal-

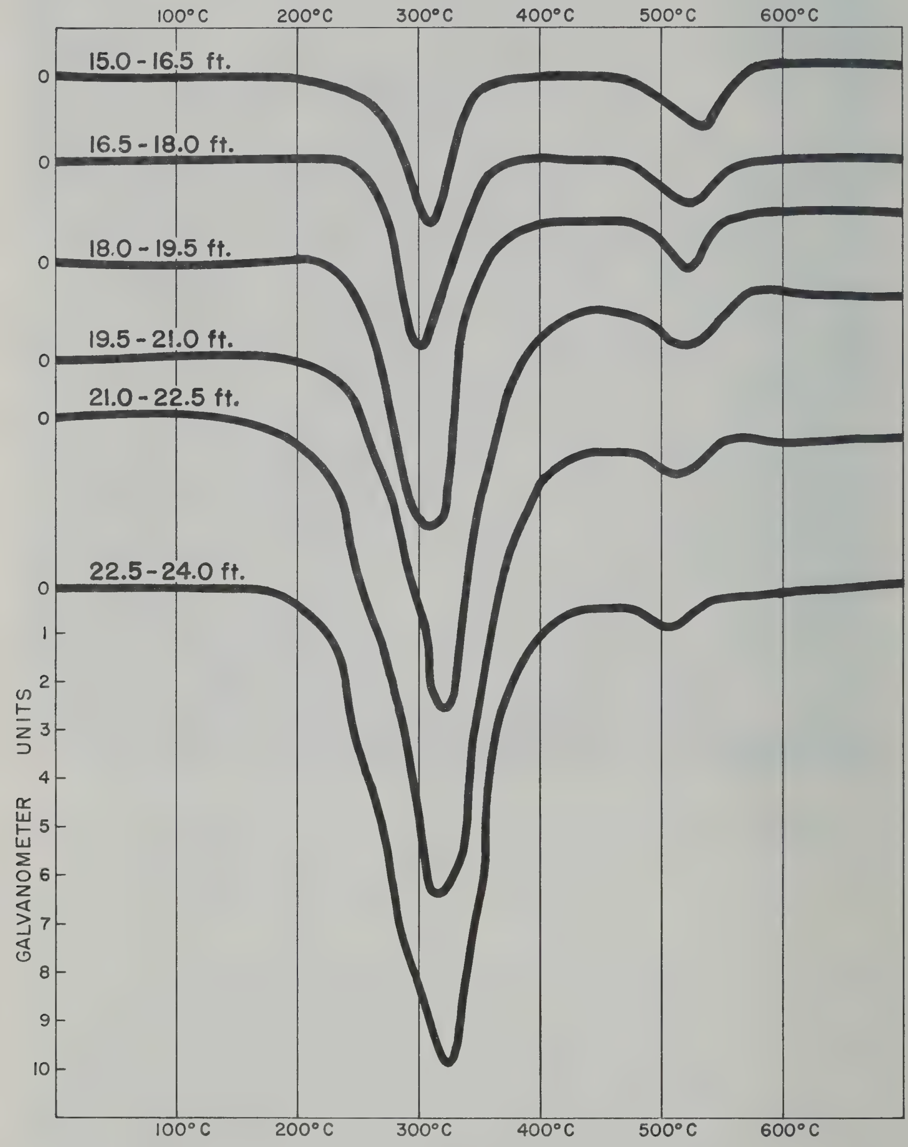


FIGURE 15.—Differential thermal analysis curves on samples from Core Hole No. 4, at 15 to 24 feet, taken every 18 inches, showing the increase in gibbsite (thermal peak 300°-340° C) upward and a corresponding decrease downward of kaolinitic clay (thermal peak 520°-540° C).

> line development of the mineral. However, when used in conjunction with other tests, such as chemical analyses, very accurate approximations can be obtained.
>
> Goethite was detected as a minor component in each of the samples. Peak height intensities indicate that the amount of goethite varies from sample to sample, following the pattern of gibbsite variation. The amount present was greatest in sample C-2163 (CH No. 2, 33-36 ft) and decreased progressively from sample C-2162 (CH No. 2, 24-27 ft) to sample C-2164 (CH No. 7, 30-33 ft).
>
> Quartz was present as a minor component in sample C-2162 (CH No. 2, 24-27 ft) and as a trace component only in samples C- 2163 (CH No. 2, 33-36 ft) and C-2164 (CH No. 7, 30-33 ft).
>
> Kaolinite-type clay, which was detected in minor amounts in all three samples by DTA, could not be positively identified from the X-ray diffraction tracings. The 4.98 Å peak, a major clay peak, is present on all three patterns; however, the 7.2 Å and 3.57 Å peaks were not detected except for the 3.57 Å peak of sample C-2164 (CH No. 7, 30-33 ft). This could have been due to the very small amount of clay in the sample or to the poor crystallinity of the clay.
>
> Strong peaks at 2.74 Å and 2.52 Å in each of the patterns have not been accounted for. These peaks may be the result of reinforced reflections from several minor components . . . .

The results were obtained by scanning at 1° per minute, using nickel-filtered copper radiation at 40 kv and 20 ma, a slit system of 1°, 006", 1', and a scale factor of 4, 1, 4. Mr. Carter has indexed the patterns, and the data are shown in Table 9.

Mr. Carter's findings regarding quartz support, in general, the suggestion made by one of the analysts (see page 76) who assayed some of the bauxite samples, that a part of the $SiO_2$ in the ore is in the form of quartz. Mr. Carter's work also indicates that there is more quartz in the samples with a high $SiO_2$ content than there is in samples with low $SiO_2$.

Two samples were identified by X-ray methods by Professor R. K. Sorem, of Washington State University. One sample was a clean white clayey material that occurred as a small spherical clot in the clay-bauxite transition zone exposed along the Fall Creek-Germany Creek road connection in the NE¼NW¼ sec. 1, T. 8 N., R. 4 W. Professor Sorem reported (written communication, 1962) that the X-ray powder pattern was identical to that of the API standard halloysite. The

TABLE 9.—Identified X-ray diffraction peaks determined on three samples of ferruginous bauxite from the Kelso-Cathlamet area [1]

| d | Peak intensity | | | Mineral |
|---|---|---|---|---|
| | CH No. 2 24-27 ft | CH No. 2 33-36 ft | CH No. 7 30-33 ft | |
| 5.01 | 4 | 4 | 6 | Goethite |
| 4.86 | 100 | 100 | 100 | Gibbsite |
| 4.37 | 46 | 33 | 47 | Gibbsite |
| 4.32 | 25 | 23 | 28 | Gibbsite |
| 4.27 | 9 | — | 4 | Quartz |
| 4.19 | 7 | 14 | 11 | Goethite |
| 3.34 | 55 | 13 | 21 | Goethite, quartz |
| 3.32 | 9 | 11 | 13 | Gibbsite |
| 3.18 | 5 | 10 | 9 | Gibbsite |
| 3.12 | 3 | 6 | 4 | Gibbsite |
| 2.70 | 18 | 14 | 13 | Goethite |
| 2.57 | 3 | 6 | 4 | Goethite |
| 2.46 | 25 | 24 | 28 | Gibbsite |
| 2.43 | 12 | 14 | 19 | Gibbsite, goethite |
| 2.39 | 18 | 23 | 21 | Gibbsite |
| 2.29 | 9 | 3 | 7 | Gibbsite |
| 2.25 | 5 | 9 | 11 | Gibbsite, goethite |
| 2.17 | 7 | 11 | 11 | Gibbsite, goethite |
| 2.05 | 9 | 9 | — | Gibbsite |
| 2.00 | 9 | 9 | 11 | Gibbsite, goethite |
| 1.92 | 2 | 7 | 6 | Gibbsite, goethite |
| 1.82 | 7 | — | — | Quartz |
| 1.80 | 7 | 9 | 5 | Gibbsite |
| 1.75 | 7 | 7 | 7 | Gibbsite |
| 1.69 | 12 | 10 | 12 | Gibbsite |

[1] X-ray analysis by George J. Carter, U.S. Bureau of Mines.

other sample, which occurred as a vug or cavity lining in a bauxite nodule (collected from a poor exposure along an old logging road in the SE¼ sec. 24, T. 9 N., R. 4 W.) was reported by Professor Sorem to be gibbsite.

## Origin of the Bauxite

Most workers agree that such things as climate, topography, drainage, ground water, and vegetation are important in the process that forms bauxite. There are two main theories, however, as to the sequence of mineralogical changes that take place in the alteration of a fresh rock to bauxite. One theory is that the aluminum silicate minerals in the parent rock are altered directly to bauxite. According to this theory, if a kaolinitic clay zone is present between the bauxite and the parent rock, the clay is the result of silicification of the bauxite. According to the second theory, an intermediate aluminum silicate clay stage between the fresh rock and the bauxite is a necessary transition. Under this theory, the feldspars and associated aluminum silicate minerals are first altered to clay, and then through continued leaching and removal of silica the clay is altered to bauxite. There is abundant evidence presented in the literature to support each of the two theories, and either or both may be valid for any given deposit. No doubt the environment of a formation has a great deal to do with the mineralogical sequence of development.

In the Kelso-Cathlamet area the laterite deposits were formed by the laterization of the top flow or flows of the Columbia River Basalt. Similarities such as ore types and the bauxite's relation to physiography and source rock indicate that the deposits of the Kelso-Cathlamet area were contemporaneous with and similar in origin to those across the Columbia River, in Washington and Columbia Counties, Oregon.

Allen (1948, p. 619-626) did a considerable amount of work on the genesis of the Oregon bauxite, and he concluded that it was formed by a two-stage process of weathering—basalt to clay to bauxite. Figure 16, reproduced from Allen's report (1948, p. 621), shows the relationship of $Al_2O_3$, $Fe_2O_3$, $SiO_2$, $TiO_2$, and $H_2O$ in a 177-foot core hole drilled in an Oregon bauxite deposit by the Alcoa Mining Company. He found that plagioclase weathered to kaolinite or to halloysite and that the ferromagnesian minerals and basaltic glass weathered to nontronite. Then, by the loss of silica, the clay minerals were altered to gibbsite and iron-rich bauxite.

In the Kelso-Cathlamet area the same conditions of formation seem to exist. In a long cut along the county road that connects the Fall Creek Road at the top of a hill (sec. 1, T. 8 N., R. 4 W.) with the Germany Creek Road at the bottom of the hill (sec. 36, T. 9 N., R. 4 W.), there is a good section where one may observe the changes that a basalt undergoes to form bauxite. At the base of the hill, fresh basalt is exposed in the roadcut. Near the top of the basalt, alteration has formed clay along the joints and fractures. Differential thermal analyses on the clay indicate that it is a kaolinite. The transition from basalt to clay is gradual, in that there is several feet of section between the fresh basalt and the level where the basalt has been completely changed to clay. In this zone there

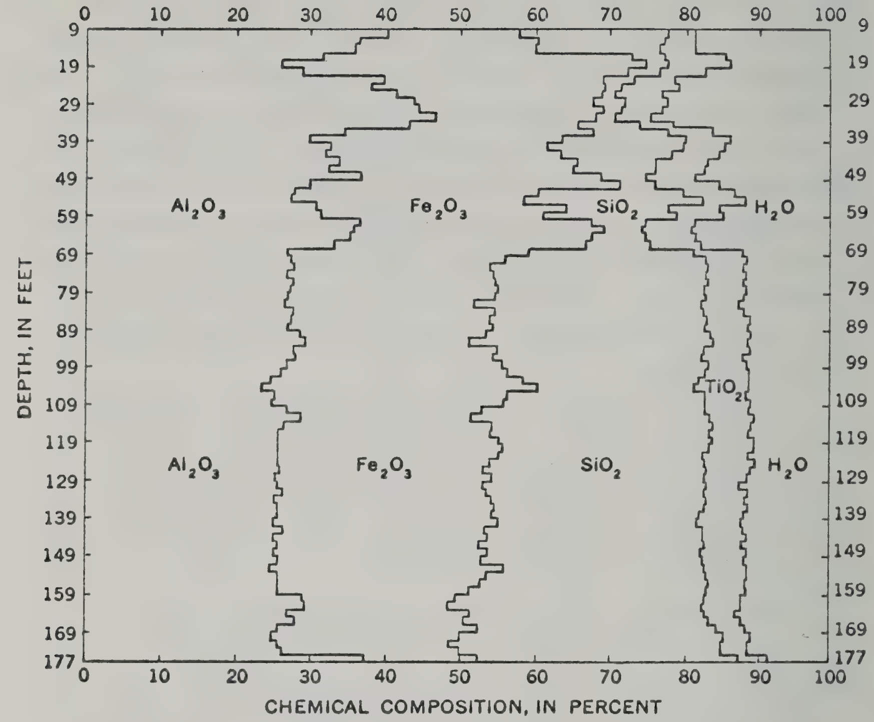


FIGURE 16. — Diagram showing variation in chemical composition with depth in a ferruginous bauxite deposit in Oregon. Analyses at 2-foot intervals by Alcoa Mining Company (Allen, 1948, p. 621).

are remnant fragments of basalt that have not been completely altered (see Fig. 17). Differential thermal analyses of clay from succeeding heights in the section reveal increasing amounts of gibbsite, until at the top, about 100 feet above the basalt, a strong gibbsite peak is present in the DTA curve. At the top of this section the laterite is composed of a soft earthy mixture of kaolinite and gibbsite, erratically distributed clots of white halloysite, and well-developed veins and nodules of gibbsite. This zone is considered to be the transition stage between the basalt and the bauxite. It is unfortunate that at this locality the bauxite has been removed by erosion; however, core hole No. 2, drilled half a mile down the ridge, cut the bauxite section, proving its presence above the transitional zone.

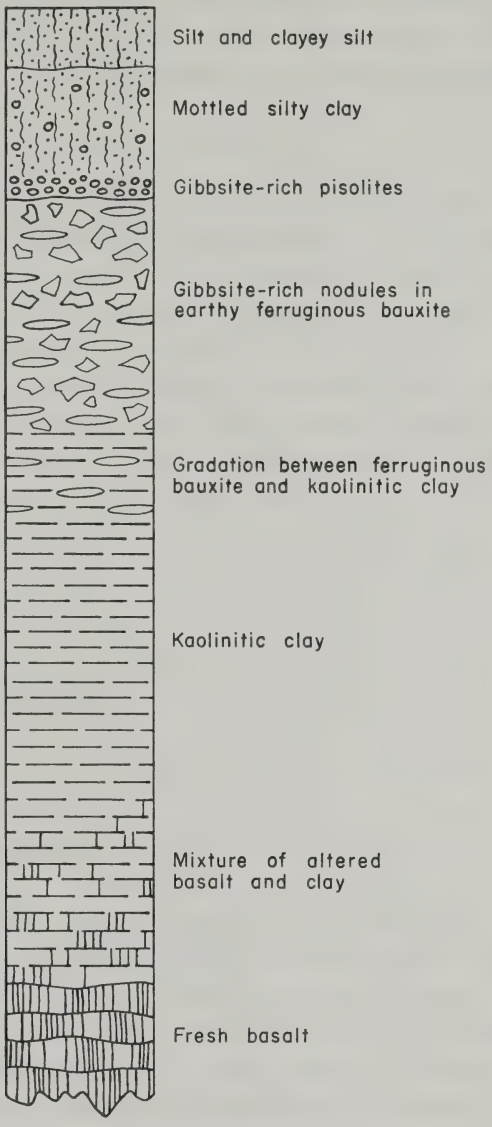

Silt and clayey silt
Mottled silty clay
Gibbsite-rich pisolites
Gibbsite-rich nodules in earthy ferruginous bauxite
Gradation between ferruginous bauxite and kaolinitic clay
Kaolinitic clay
Mixture of altered basalt and clay
Fresh basalt

FIGURE 17.—Diagrammatic section from the surface through the bauxite horizon to fresh basalt in the Kelso-Cathlamet area. The lower part of this section, between the gradational zone and the fresh basalt, can be seen in roadcuts along a road connecting the Fall Creek and Germany Creek roads, in the NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 1, T. 8 N., R. 4 W.

The alteration of basalt to kaolin, coupled with the increased abundance of gibbsite up-section, is interpreted as being good evidence for the intermediate clay stage between the parent rock and the bauxite.

## Analyses of Samples

During the course of this investigation ten core holes (see Fig. 23, in pocket) were drilled at various places in the area with a Bucyrus-Erie Model 20-W drill. The holes were cored continuously, and cores were taken in 18-inch sections. In addition, three channel samples from roadcuts were taken for analysis.

Drilling was restricted to lands not already controlled by aluminum companies, and, because company ownership covered much of the area that appears to be most favorable for the occurrence of bauxite, it was difficult to find good locations to drill. Only four of the core holes, CH No. 2, CH No. 4, CH No. 6, and CH No. 7, cut ore sections. Three of the holes, CH No. 3, CH No. 8, and CH No. 10, were drilled in sedimentary sections, probably Miocene beach sands and conglomerate. Two of the holes, CH No. 5 and CH No. 9, were drilled in areas where the bauxite apparently had been eroded away and only the intermediate kaolinitic clay zone remained. Core hole No. 1 was drilled along the brink of a hill, where either slumping had allowed some of the overlying silty clay to work down into the bauxite or else most of the bauxite had been eroded away and the hole was in the top of the transition zone.

Differential thermal analysis showed that every hole contained some gibbsitic material. At least one analysis is given for each hole (Table 11, pages 78-87). For holes that show only one analysis, that analysis was made on the core that gave the strongest thermic peak for gibbsite.

The analytical work done on the samples showed that the chemical analyses did not fully agree with the differential thermal analyses. The DTA consistently showed less silica than did the chemical analyses. This may be explained by the fact that the silica content as determined by DTA was assumed to be present entirely as kaolin, but quartz grains were found when some of the samples were washed. This quartz did not show by DTA, but did add to the silica content determined by chemical analysis. One analyst suggested that from 1/6 to 1/4 of the $SiO_2$ reported by chemical analysis of these samples is present in the samples in the form of quartz. Because of the large discrepancy between the two methods of analysis, several samples were split and sent to several analysts for check assays. Table 10 shows the results of their work.

TABLE 10. — Check analyses of duplicate samples by six analysts[1]

| Sample | Analyst[2] | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | Loss on ignition | $V_2O_5$ |
|---|---|---|---|---|---|---|---|
| CH No. 2, 24-27 ft | 1 | 41.32 | 16.01 | 18.74 | 0.99 | 24.28 | — |
| Do | 2 | 40.0 | 11.7 | 21.9 | — | 21.7 | — |
| Do | 3 | — | — | — | — | — | 0.132 |
| Do | 4 | — | 11.96 | — | — | 23.40 | — |
| Do | [3] 5 | (40.6 38.7 39.3) | 13.4 | 14.4 | 5.04 | 22.7 | — |
| Do | 6 | 42.6 | 8.9 | 22.7 | 6.70 | 24.28 | — |
| CH No. 2, 33-36 ft | 1 | 37.97 | 7.10 | 30.34 | 2.28 | 23.93 | — |
| Do | 2 | 39.9 | 6.49 | 27.0 | — | 22.5 | — |
| Do | 3 | — | — | — | — | — | 0.117 |
| Do | 6 | 38.6 | 5.9 | 30.05 | 5.05 | 22.93 | — |
| CH No. 4, 21-24 ft | 1 | 37.88 | 23.27 | 17.55 | 0.52 | 21.76 | — |
| Do | 2 | 38.1 | 20.8 | 19.5 | — | 18.8 | — |
| Do | 3 | — | — | — | — | — | 0.089 |
| Do | 4 | — | 20.04 | — | — | 20.90 | — |
| Do | 6 | 39.2 | 15.8 | 26.0 | 2.15 | 21.76 | — |
| CH No. 9, 22½-25½ ft | 1 | 35.82 | 15.52 | 26.77 | 0.83 | 22.84 | — |
| Do | 4 | — | 11.78 | — | — | 22.55 | — |
| Do | 6 | 36.6 | 9.55 | 30.0 | 4.5 | 22.84 | — |
| CH No. 7, 30-33 ft | 1 | 45.25 | 1.22 | 28.55 | 4.20 | 23.41 | — |
| Do | 2 | 40.1 | 5.87 | 27.0 | — | 22.4 | — |
| Do | 3 | — | — | — | — | — | 0.119 |
| Do | 6 | 36.0 | 4.55 | 30.06 | 5.75 | 23.41 | — |
| CZ No. 2, 10-13 ft | 1 | 44.06 | 5.68 | 24.69 | 1.40 | 25.06 | — |
| Do | 2 | 44.1 | 3.06 | 24.4 | — | 24.7 | — |
| Do | 3 | — | — | — | — | — | 0.111 |

---

[1] Analysts 1 through 5 used chemical methods (see Appendix A, on page 97, for analytical procedures), and analyst 6 used the X-ray spectrograph.

[2] Analysts are as follows: 1. Northwest Testing Laboratories, Portland, Oregon; 2. Colorado School of Mines Research Foundation, Inc., Golden, Colorado; 3. Root & Simpson, Denver, Colorado; 4. L. L. Hoagland, of the State of Oregon Department of Geology and Mineral Industries, Portland, Oregon; 5. Metallurgical Laboratory, Seattle, Washington; 6. D. R. Fenton, of the University of Washington Department of Oceanography, Seattle, Washington.

[3] See Appendix A for three different analytical procedures used for $Al_2O_3$. Procedures are given in order of analysis.

TABLE 11. — Chemical analyses of samples that were highest

(Analyst, Northwest Testing

| Interval (feet) | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | Loss on ignition | P |
|---|---|---|---|---|---|---|
| | | | | | | CH No. 1 (NE¼SE¼ |
| 18-21 | 32.05 | 24.93 | 23.50 | 2.90 | 17.58 | -------- |
| | | | | | | CH No. 2 (NW¼SE¼ |
| 21-24 | 37.81 | 20.64 | 19.34 | 1.00 | 23.07 | -------- |
| 24-27 | 41.32 | 16.01 | 18.74 | 0.99 | 24.28 | -------- |
| 27-30 | 30.78 | 13.98 | 32.72 | 0.62 | 22.64 | -------- |
| 30-33 | 40.67 | 8.23 | 26.18 | 3.00 | 22.52 | -------- |
| | | | | | | [1] 0.20 |
| 33-36 | 37.97 | 7.10 | 30.34 | 2.28 | 23.93 | -------- |
| 36-39 | 33.27 | 10.69 | 35.40 | 1.58 | 19.30 | -------- |
| 39-42 | 35.72 | 9.16 | 32.42 | 2.82 | 19.88 | -------- |
| 42-45 | 40.15 | 10.32 | 26.17 | 2.00 | 22.29 | -------- |
| 45-48 | 33.62 | 13.56 | 31.83 | 3.62 | 18.31 | -------- |
| 48-51 | 28.14 | 27.95 | 26.23 | 2.33 | 16.16 | -------- |

---

[1] Composite sample, 21-51 ft.

in $Al_2O_3$ as indicated by differential thermal analyses

Laboratories, Portland, Oregon)

| Core description |
|---|
| sec. 6, T. 8 N., R. 3 W.) |
| Mottled red, gray, and purplish clayey matrix containing mustard-yellow gibbsite nodules. |
| sec. 1, T. 8 N., R. 4 W.) |
| Bottom part of core is mottled rust-red, gray, and brown silty clay that has black manganese seams. Pisolites are abundant. Bottom is rust-red earthy clay matrix containing mustard-yellow gibbsite nodules. |
| Mottled rust-red and reddish-brown earthy clay containing hard brown rindlike iron oxide nodules, reddish-brown pisolites, and mustard-yellow gibbsite nodules. |
| Mottled as above; a few clots of white clay are present. |
| Mottled as above, but earthy matrix is lighter in color. |
| |
| Mottled as above; pisolites are less abundant. |
| Mostly mottled and earthy as above; gibbsite nodules are less abundant. Bottom part of core has irregular red and tan banding developed in the clay. |
| Mottled and banded as above with soft earthy chocolate-brown clots. Small nodules are abundant in bottom part. |
| Mottled and banded as above; banding appears to have formed along fractures in the original rock. |
| Mottled and banded as above; nodules are scarce. |
| Mottled red to red-brown; has appearance of being brecciated. Hard parts of core are rich red in color and vesicular. Joints are coated with a black manganese mineral. Overall appearance is that of altered volcanic rock. |

TABLE 11.—Chemical analyses of samples that were highest in

| Interval (feet) | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | Loss on ignition | P |
|---|---|---|---|---|---|---|
| | | | | | | CH No. 3 (NW$\frac{1}{4}$NW$\frac{1}{4}$ |
| 21-27 | 29.80 | 36.99 | 14.87 | 2.38 | 15.33 | -------- |
| | | | | | | CH No. 4 (SE$\frac{1}{4}$SE$\frac{1}{4}$ |
| 21-24 | 37.88 | 23.27 | 17.55 | 0.52 | 21.76 | -------- |
| 24-27 | 43.27 | 12.38 | 23.20 | 0.40 | 22.56 | -------- |
| 27-30 | 41.73 | 11.84 | 24.98 | 0.64 | 22.18 | -------- |
| | | | | | | [2] 0.24 |
| 30-33 | 37.34 | 14.26 | 29.56 | 4.35 | 15.95 | -------- |
| 33-36 | 29.04 | 18.68 | 29.15 | 3.90 | 15.76 | -------- |
| 36-39 | 27.88 | 32.96 | 21.72 | 3.50 | 15.53 | -------- |
| | | | | | | CH No. 5 (NW$\frac{1}{4}$SE$\frac{1}{4}$ |
| 27-30 | 33.18 | 16.99 | 28.55 | 3.62 | 19.56 | -------- |

---

[2] Composite sample, 21-39 ft.

$Al_2O_3$ as indicated by differential thermal analyses—Continued

| Core description |
|---|
| sec. 27, T. 9 N., R. 4 W.) |
| Rust-red silty clay containing scattered iron-rich hard brown pisolites. Bottom few inches of core contains weathered pebble conglomerate. |
| sec. 28, T. 9 N., R. 4W.) |
| Mottled rust-red and light-brown silty clay at top, becoming redder at bottom. Abundant dark-brown pisolites. Clastic quartz and muscovite grains are visible in both matrix and pisolites. |
| Mottled as above; pisolites as much as 1 inch in diameter are present. Matrix is clay; no clastic mineral grains are visible. |
| Same as above. |
| Mottled as above, but overall hue is more brown; pisolites are less distinct. Material appears to be transported. |
| Olive-gray clay at top that is quite nodular. Nodules are same color as matrix. Bottom part of core contains fragments that look like brown altered basalt but are probably gibbsitic nodules. |
| Mottled as above; has fragmented texture. Overall color tends to be more brown. |
| sec. 2, T. 8 N., R. 5 W.) |
| Red clay containing abundant brown iron pisolites. Some of the larger ones have a hard iron coating around an olive-brown center. Contains lighter red bands. |

TABLE 11.—Chemical analyses of samples that were highest in

| Interval (feet) | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | Loss on ignition | P |
|---|---|---|---|---|---|---|
| CH No. 6 (SW¼NW¼ | | | | | | |
| 18-21 | 29.07 | 31.66 | 22.91 | 2.38 | 15.24 | -------- |
| 21-24 | 33.58 | 13.96 | 28.85 | 2.82 | 21.71 | -------- |
| 24-27 | 30.25 | 12.08 | 34.80 | 2.60 | 20.57 | -------- |
| | | | | | | [3] 0.60 |
| 27-30 | 38.17 | 10.62 | 28.55 | 4.20 | 20.81 | -------- |
| 30-33 | 34.23 | 21.20 | 24.98 | 3.60 | 17.07 | -------- |
| 33-36 | 30.87 | 27.20 | 23.80 | 2.60 | 15.56 | -------- |
| 36-39 | 34.72 | 16.80 | 27.37 | 3.35 | 19.62 | -------- |
| CH No. 7 (SE¼NW¼ | | | | | | |
| 30-33 | 45.25 | 1.22 | 28.55 | 4.20 | 23.41 | -------- |
| 33-36 | 34.94 | 10.60 | 30.04 | 2.82 | 23.08 | -------- |
| | | | | | | [4] 0.70 |
| 36-39 | 36.18 | 14.44 | 26.77 | 3.90 | 19.50 | -------- |

---

[3] Composite sample, 18-39 ft.

[4] Composite sample, 30-45 ft.

$Al_2O_3$ as indicated by differential thermal analyses—Continued

| Core description |
|---|
| sec. 31, T. 9 N., R. 3 W.) |
| Red clay containing abundant brown iron pisolites. |
| Top part, as above, is separated from mottled rust-brown and olive-gray clay below by a sharp contact. A few rust-red to light-brown pisolites are in the bottom part. |
| Mottled reddish-brown to olive-brown earthy clay. Pisolites are fairly abundant. Hard olive-brown nodules are present. A few white clots of halloysite(?) occur. |
| |
| Same as above; more nodules are present. Some nodules are vesicular. |
| Same as above. Bottom part of the core looks like altered basalt, quite vesicular. |
| Mottled purple, rust-brown, and gray earthy clay containing hard nodules, not as hard as above. Fractures have a black manganese coating. |
| Same as above. Black manganese fracture coating is more abundant. |
| sec. 25, T. 9 N., R. 4 W.) |
| Top half of the core is red silty clay containing abundant brown iron pisolites. Bottom half is olive-brown homogeneous earthy clay containing vesicular fragments and becoming slightly mottled with red at the bottom. |
| Same as bottom part of the core above. Red mottling increases downward. |
| |
| Same as above; joints in bottom part of the core are coated with a black manganese mineral. |

TABLE 11.—Chemical analyses of samples that were highest in

| Interval (feet) | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | Loss on ignition | P |
|---|---|---|---|---|---|---|
| CH No. 7 (SE¼NW¼ sec. 25, | | | | | | |
| 39-42 | 34.21 | 19.16 | 24.39 | 1.40 | 22.09 | -------- |
| 42-45 | 36.81 | 18.04 | 25.58 | 3.36 | 18.40 | -------- |
| CH No. 8 (SW¼SW¼ | | | | | | |
| 27-33 | 28.38 | 22.23 | 27.42 | 5.35 | 16.66 | -------- |
| CH No. 9 (SE¼SE¼ | | | | | | |
| 19½-22½ | 38.07 | 30.54 | 11.90 | 0.83 | 20.44 | -------- |
| 22½-25½ | 35.82 | 15.52 | 26.77 | 0.83 | 22.84 | -------- |
| 25½-28½ | 32.27 | 18.82 | 28.26 | 2.05 | 19.39 | -------- |
| CH No. 10 (SW¼SW¼ | | | | | | |
| 16-21 | 29.64 | 36.26 | 16.06 | 2.85 | 15.92 | -------- |
| F. C. (NE¼NW¼ sec. 1, T. 8 N., | | | | | | |
| 78-81 | 39.75 | 20.86 | 17.55 | 0.75 | 23.36 | ------ |
| 81-84 | 39.70 | 14.92 | 18.15 | 2.70 | 23.55 | |
| 84 89 | 29.39 | 23.87 | 24.96 | 3.20 | 17.93 | |

$Al_2O_3$ as indicated by differential thermal analyses—Continued

| Core description |
|---|
| T. 9 N., R. 4 W.)—Continued |
| Same as above; the texture is distinctly vesicular; the rock looks very much like an altered volcanic. |
| Same as above; manganese coating along fractures becoming heavier. |
| sec. 34, T. 9 N., R. 3 W.) |
| Upper half is buff-brown clayey siltstone mottled with light red. Bottom is round pebble conglomerate in a sandy matrix. All pebbles have been altered to clay. |
| sec. 1, T. 8 N., R. 5 W.) |
| Light-red clay mottled with gray. Brown iron pisolites and rindlike clots as much as 1 inch in diameter are abundant. Quartz grains also are abundant. |
| Top is same as above. Bottom is mottled olive-brown and red earthy clay. Hard fragments have a basaltic texture. |
| Same as bottom part of the core above. Overall color is more brown. White clots are fairly common. |
| sec. 22, T. 9 N., R. 4 W.) |
| Red silty clay with a few light-brown streaks, and soft red iron clots. |
| R. 4 W.) Channel sample from roadcut |
| Mottled brown, olive-brown, red, and white clay. Overall color is olive brown. Earthy matrix with hard gibbsite nodules. Appears to have relict joint pattern and fractures coated with black manganese. White clots are halloysite. |

TABLE 11.—Chemical analyses of samples that were highest in

| Interval (feet) | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | Loss on ignition | P |
|---|---|---|---|---|---|---|
| CZ No. 2 (NW¼NE¼ sec. 30, T. 9 N., | | | | | | |
| 7-10 | 46.27 | 8.32 | 16.63 | 1.30 | 27.15 | ------ |
| 10-13 | 44.06 | 5.68 | 24.69 | 1.40 | 25.06 | |
| 13-16 | 42.31 | 5.56 | 24.99 | 1.95 | 27.52 | |
| 16-19 | 33.17 | 7.51 | 35.99 | 0.95 | 22.93 | |
| 19-22 | 37.26 | 8.18 | 30.94 | 2.15 | 21.86 | |
| 22-25 | 32.87 | 19.42 | 25.28 | 2.50 | 21.57 | |
| Ca 77 (NE¼SW¼ sec. 23, T. 9 N, | | | | | | |
| 1-5 | 39.5 | 8.27 | 26.6 | ---- | 22.0 | -------- |

$Al_2O_3$ as indicated by differential thermal analyses— Continued

| Core description |
|---|
| R. 3 W.) Channel sample from roadcut |
| Mottled reddish-brown and olive-brown clay. Quite hard and brittle. Toward bottom of the cut, black manganese coating fracture walls is abundant. |
| R. 5 W.) Channel sample from roadcut |
| Mottled reddish-brown to olive-brown clay containing reddish-yellow gibbsite-rich nodules. |

TABLE 12.—Assay record of samples from a core hole drilled in Cowlitz County by the Reynolds Metals Company[1]

| Sample interval (feet) | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | $TiO_2$ | Loss on ignition |
|---|---|---|---|---|---|
| 18.0 - 20.5 | 29.92 | 35.35 | 16.70 | 3.10 | 14.93 |
| 20.5 - 23.0 | 32.27 | 11.18 | 33.20 | 5.02 | 18.33 |
| 23.0 - 25.5 | 44.05 | 5.52 | 21.60 | 3.86 | 24.97 |
| 25.5 - 28.0 | 46.05 | 3.17 | 20.80 | 3.96 | 26.02 |
| 28.0 - 30.5 | 42.07 | 4.46 | 25.20 | 4.18 | 24.09 |
| 30.5 - 33.0 | 41.33 | 4.58 | 26.50 | 4.38 | 23.21 |
| 33.0 - 35.5 | 42.95 | 3.45 | 25.40 | 4.18 | 24.02 |
| 35.5 - 38.0 | 37.67 | 6.88 | 29.70 | 4.70 | 21.05 |
| 38.0 - 40.5 | 33.43 | 13.61 | 30.20 | 4.50 | 18.26 |
| 40.5 - 43.0 | 36.64 | 14.03 | 25.80 | 4.18 | 19.35 |
| 43.0 - 45.5 | 36.92 | 12.90 | 26.40 | 4.18 | 19.60 |
| 45.5 - 48.0 | 32.97 | 18.09 | 27.80 | 4.50 | 16.64 |
| 48.0 - 50.5 | 33.40 | 21.42 | 24.70 | 3.96 | 16.52 |
| 50.5 - 53.0 | 29.23 | 28.10 | 24.60 | 3.86 | 14.21 |

[1] Information supplied by the Reynolds Metals Company.

TABLE 13.—Average of analyses of ferruginous bauxite from Cowlitz County, Washington, as compared with the average of analyses of ferruginous bauxite from Columbia County, Oregon[1]

| | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | $TiO_2$ |
|---|---|---|---|---|
| Cowlitz County, Wash. .... | 38 | 6.0 | 27 | 4.0 |
| Columbia County, Oreg. .. | 34 | 6.5 | 33 | 5.0 |

[1] Information supplied by Harvey Aluminum, Incorporated. These analyses represent many samples.

Generally speaking, the laterite from the Kelso-Cathlamet area has slightly higher alumina and iron contents than do the ores from Oregon; however, the titanium content is less in the Washington ore (Table 13).

TABLE 14.—Average of analyses of laterite from Cowlitz County based on several thousand samples taken by the Aluminum Company of America[1]

| | Percent |
|---|---|
| $Al_2O_3$ | 38.8 |
| $SiO_2$ | 6.6 |
| $Fe_2O_3$ | 28.7 |
| $TiO_2$ | 4.2 |
| Loss on ignition | 21.7 |
| Total | 100.0 |

[1] Information supplied by the Aluminum Company of America.

## Economics of the Bauxite

Only high-grade bauxite can be satisfactorily treated by the Bayer process for the extraction of aluminum, and the ferruginous bauxite deposits of southwest Washington definitely cannot be considered as high grade. Whereas a typical bauxite ore from Arkansas contains between 55 and 65 percent $Al_2O_3$, the ferruginous bauxite of southwest Washington usually contains only about 30 to 40 percent $Al_2O_3$.

In order to increase the economic feasibility of using the ferruginous bauxite as a source of aluminum, the iron content of the laterite should be utilized, if possible. The Pedersen process of extracting the iron from ferruginous bauxite has been used in Norway since 1928. In this method as originally developed, scrap iron, ferruginous bauxite, and lime were charged in an electric furnace. The iron was drawn off as pig, and the slag—calcium aluminate—was pulverized and run through an extracting solution.

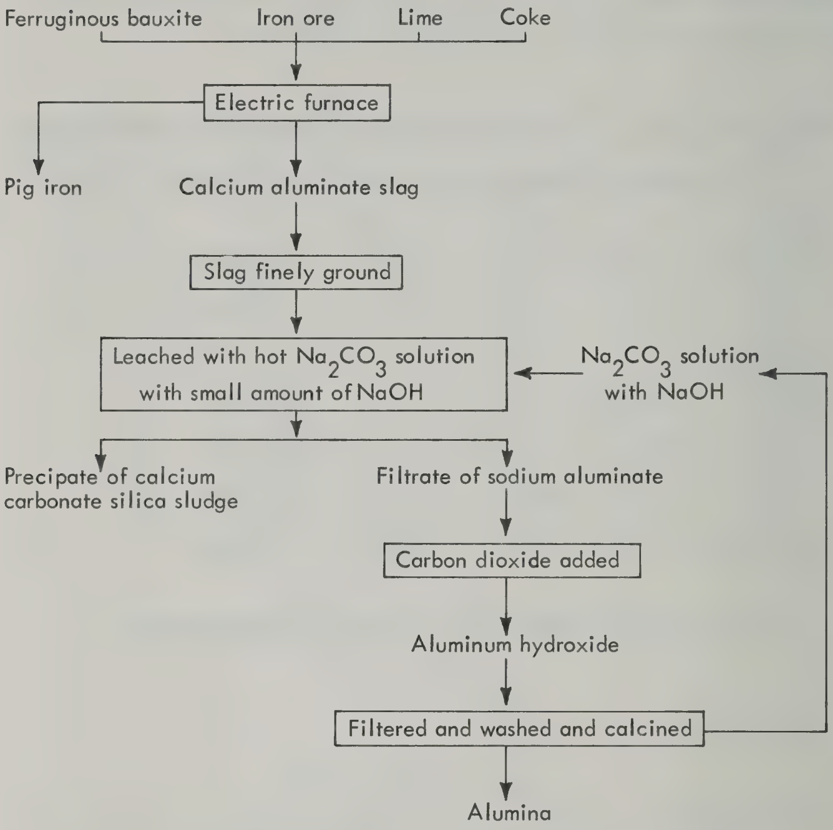

Ferruginous bauxite
Iron ore
Lime
Coke
Electric furnace
Pig iron
Calcium aluminate slag
Slag finely ground
Leached with hot $Na_2CO_3$ solution with small amount of NaOH
$Na_2CO_3$ solution with NaOH
Precipitate of calcium carbonate silica sludge
Filtrate of sodium aluminate
Carbon dioxide added
Aluminum hydroxide
Filtered and washed and calcined
Alumina

FIGURE 18.—Flowsheet of the Pedersen method of producing alumina and pig iron from ferruginous bauxite.

Chittenden and Moulton (1951) ran tests at the University of Washington on Oregon laterite, using the Pedersen process. They were able to separate the iron and calcium aluminate slag readily, but experienced considerable difficulty in extracting the alumina from the slag. The chemical equation for reducing the slag to alumina is as follows:

$$\underset{\text{(slag)}}{CaO\cdot Al_2O_3} + Na_2CO_3 = CaCO_3 + Na_2Al_2O_4$$

$$Na_2Al_2O_4 + CO_2 + 3\ H_2O = Al_2O_3\cdot 3\ H_2O + Na_2CO_3$$

TABLE 15.—Results of seven test runs using the Pedersen process[1]

| RUN | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| VARIABLE UNDER STUDY | Optimum | Large Excess Carbon | Excess Carbon | Insufficient Carbon | Excess Limestone | Insufficient Limestone | Additional $Fe_2O_3$ |
| FEED CHARGED TO FURNACE (lb) | | | | | | | |
| Laterite | 20 | 8.45 | 20 | 20 | 20 | 20 | 20 |
| Limestone | 14 | 5.4 | 14 | 14 | 19 | 9 | 14 |
| Carbon | 1.4 | 1.0 | 2.0 | 0.7 | 1.4 | 1.4 | 1.4 |
| $Fe_2O_3$ | ... | ... | ... | ... | ... | ... | 4.2 |
| Graphite lost by electrode | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 |
| Graphite lost by crucible | 1 | 2 | 1 | 1 | 1.25 | 1.5 | 1 |
| Actual carbon consumed | 3.65 | 4.25 | 4.65 | 2.95 | 3.9 | 4.15 | 3.65 |
| CONDITIONS OF RUN | | | | | | | |
| Average temperature (°C) | 1600 | 1700 | 1600 | 1600 | 1600 | 1600 | 1600 |
| Duration of run (hr) | 4 | 5 | 7 | 6.5 | 5 | 4.5 | 5.75 |
| Average current reading (amp) | 450 | 400 | 400 | 400 | 450 | 450 | 400 |
| Average voltage reading (v) | 45 | 45 | 45 | 45 | 45 | 45 | 45 |
| Electrical energy (kwhr) | 64.3 | .... | 111.3 | 87.8 | 79.7 | 71.8 | 76.0 |
| PRODUCTS OBTAINED (lb) | | | | | | | |
| Slag | 14.62 | .... | 15.25 | 16.25 | 17.5 | 14.5 | 17.75 |
| Alloy | 3.5 | .... | 3.12 | 2.96 | 3.14 | 3.25 | 3.25 |
| Unfused | 0.98 | .... | 1.21 | 1.05 | 2.35 | 0.42 | 2.78 |
| Unfused lost as dust | 0.25 | .... | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Total weight | 19.35 | .... | 19.83 | 20.51 | 23.24 | 18.42 | 24.03 |
| ANALYSIS OF SLAG (%) | | | | | | | |
| $Al_2O_3$ | 42.10 | 39.30 | 45.20 | 40.80 | 40.80 | 50.70 | 40.60 |
| FeO | 4.72 | 1.30 | 6.23 | 9.83 | 6.79 | 4.95 | 16.23 |
| $SiO_2$ | 8.42 | 9.20 | 8.30 | 7.65 | 6.52 | 9.08 | 7.85 |
| $TiO_2$ | 3.71 | 1.00 | 5.12 | 3.30 | 2.92 | 3.82 | 4.46 |
| CaO | 41.05 | 49.20 | 35.15 | 38.42 | 42.97 | 31.45 | 30.86 |
| C | Trace | Trace | Trace | Trace | Trace | Trace | Trace |
| ANALYSIS OF ALLOY (%) | | | | | | | |
| Al | 4.3 | 6.9 | 5.8 | 5.0 | 2.6 | 2.1 | 7.6 |
| Fe | 93.2 | 86.9 | 92.5 | 87.3 | 94.5 | 95.1 | 89.8 |
| Si | 0.1 | 2.9 | 0.3 | 0.7 | 0.1 | 0.1 | 0.0 |
| Ti | 2.0 | 3.4 | 0.3 | 2.0 | 1.9 | 1.7 | 0.62 |
| C | Trace | Trace | Trace | Trace | Trace | Trace | Trace |
| EXTRACTION OF ALUMINA (g) (20 g of slag treated with 200 g extracting solution) | | | | | | | |
| 1st extraction | 1.34 | 0.94 | 1.50 | 1.94 | 0.64 | 1.95 | 1.11 |
| 2nd extraction | 0.36 | | | | | | |
| 3rd extraction | 0.11 | | | | | | |

[1] Tests were made in a 25-kva furnace, keeping the laterite charge constant and varying one constituent on each run. From Chittenden and Moulton (1951, p. 21).

In their conclusions, Chittenden and Moulton (1951, p. 21) said:

> The application of the Pedersen process to the Oregon laterites produces a dense, hard, metallic alloy of iron and a calcium aluminate slag.
>
> A large excess of carbon results in the reduction of alumina and titania to the metallic form. Dusting of one slag was also noted when a large excess of carbon was used. An insufficient amount of carbon resulted in the incomplete reduction of the iron and the presence of a higher percentage of FeO in the slag.
>
> The addition of ferric oxide to the charge of laterite, limestone, and carbon resulted in the incomplete reduction of iron. The presence of high percentages of ferrous oxide in the slag resulted in oxidation of the

> silicon to silica, keeping it in the slag. No silicon was found in the alloy of this run (Run No. 7).
>
> The extraction of alumina from the slag left much to be desired. There was no apparent reason why such a small percentage of alumina was extractable. The recovery of alumina was approximately only 20 percent of the alumina in the slag. Each additional stage of extraction recovered less than one-third of the alumina obtained in the previous extraction.
>
> The titania in the laterite on fusion in the furnace is found both in the slag and the iron alloy. The recovery of titania from the residue left after extracting the alumina does not appear to be economically attractive. The titania in the laterite would not increase the value of the ore in this method of processing.

The U.S. Bureau of Mines has been working for several years on the problem of extracting alumina from low-grade bauxite. The results of some of their work are reported by McCarthy and others (1949), Thompson and others (1949), and Holbrook and Yerkes (1963). Holbrook and Yerkes (1963, p. 20) report that 80 percent of the alumina from the Oregon bauxite can be recovered by a double-leach process and that such a process would provide a possible method for the production of alumina.

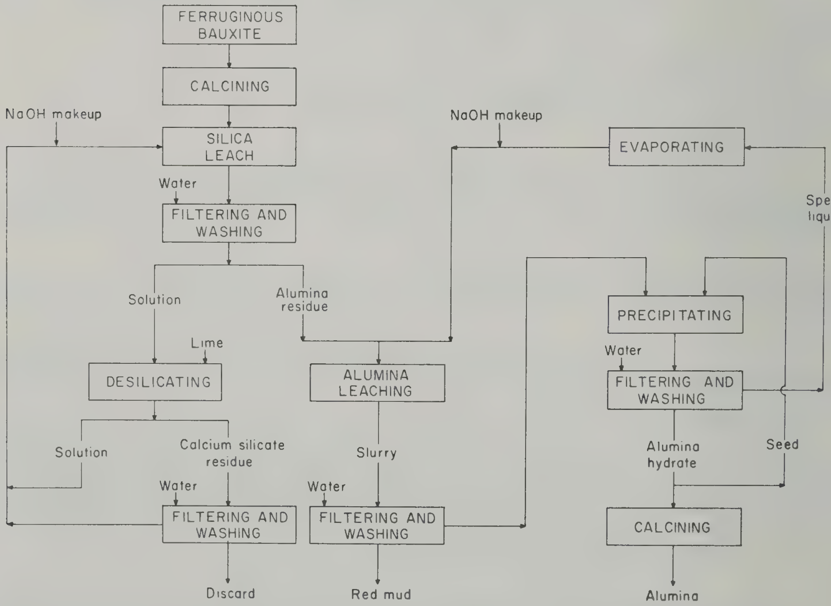

FERRUGINOUS BAUXITE
CALCINING
NaOH makeup
SILICA LEACH
Water
FILTERING AND WASHING
Solution
Alumina residue
Lime
DESILICATING
Solution
Calcium silicate residue
Water
FILTERING AND WASHING
Discard
NaOH makeup
EVAPORATING
Spent liquor
ALUMINA LEACHING
Slurry
Water
FILTERING AND WASHING
Red mud
PRECIPITATING
Water
FILTERING AND WASHING
Alumina hydrate
Seed
CALCINING
Alumina

FIGURE 19.—Flowsheet of double-leach process of Holbrook and Yerkes (1963, p. 19).

An acid leach process developed by T. R. Scott, of the Commonwealth Scientific and Industrial Research Organization, of Melbourne, Australia, is outlined

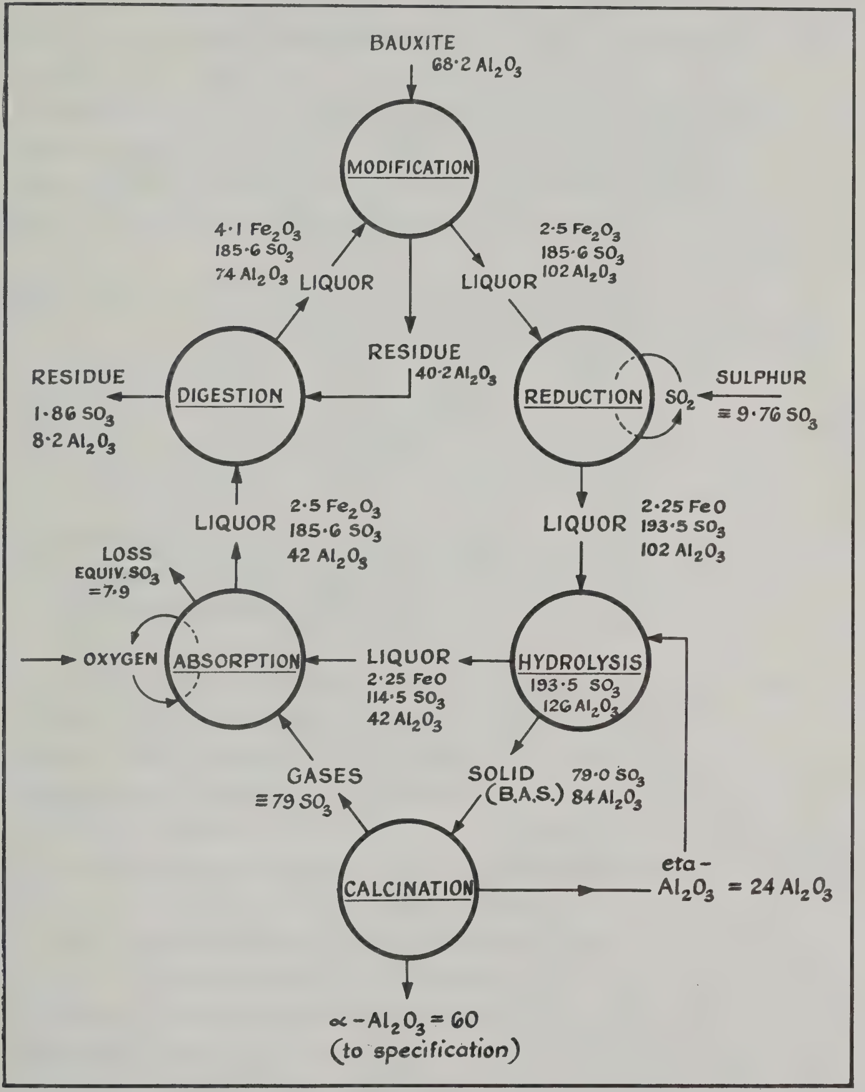

BAUXITE
68·2 Al2O3
MODIFICATION
4·1 Fe2O3
185·6 SO3
74 Al2O3
LIQUOR
LIQUOR
2·5 Fe2O3
185·6 SO3
102 Al2O3
RESIDUE
40·2 Al2O3
RESIDUE
1·86 SO3
8·2 Al2O3
DIGESTION
REDUCTION
SO2
SULPHUR
≡ 9·76 SO3
LIQUOR
2·5 Fe2O3
185·6 SO3
42 Al2O3
LIQUOR
2·25 FeO
193·5 SO3
102 Al2O3
LOSS
EQUIV. SO3
=7·9
OXYGEN
ABSORPTION
LIQUOR
2·25 FeO
114·5 SO3
42 Al2O3
HYDROLYSIS
193·5 SO3
126 Al2O3
GASES
≡79 SO3
SOLID
(B.A.S.)
79·0 SO3
84 Al2O3
CALCINATION
eta-
Al2O3 = 24 Al2O3
∝-Al2O3 = 60
(to specification)

FIGURE 20.—Flowsheet of Commonwealth Scientific and Industrial Research Organization process for alumina extraction. Quantities are expressed in gm/liter, assuming approximately 60 percent net hydrolysis yield, and 88 percent recovery of alumina from the ore. From Scott (1962, p. 121).

in the flowsheet shown in Figure 20. In 1963 Scott made tests on a sample of Washington ore, using his process, and reported as follows (written communication, 1963):

> The major purpose of our tests has been to ensure that the ore responds suitably during the two-stage digestion required by our process (see flow sheet, J. Metals, Feb. 1962, p. 121). Once a basic digestion liquor is obtained with an $SO_3:Al_2O_3$ ratio of 1.95 or lower and an $Fe_2O_3:Al_2O_3$ ratio of less than 0.10, we know from previous experience that the remaining stages of the process can be carried out successfully to produce high-grade alumina (0.01% $SiO_2$ and 0.02% Fe) in good yield.
>
> Since the digestion procedure is essentially a two-stage, countercurrent extraction, the following tests are required:
>
> (i) Prepare an acid digestion liquor (ratio $SO_3:Al_2O_3$ approximately 2.6) by heating fresh acid and the appropriate amount of ore at 180° C for 30 minutes. According to the flow sheet, a concentration of around 75 gm./l. $Al_2O_3$ is required in this solution.
>
> (ii) Treat the acid digestion liquor with additional ore at 130° C for 30 minutes, so as to obtain a basic ("modified") digestion liquor having a concentration of around 102 gm./l. $Al_2O_3$ at an $SO_3:Al_2O_3$ ratio of less than 1.95.
>
> (iii) React the residual, partly extracted ore from step (ii) with recycled acid liquor from the later stages of the process. We generally use a synthetic recycle liquor here, with a composition as shown in the flow sheet. The object of the third step is to obtain—
>
> (a) digestion liquor of a composition similar to that attained in step (i), and
>
> (b) solid residue representing ore from which at least 80% of the alumina has been extracted.
>
> Successful operation of step (iii) confirms that the countercurrent extraction procedure is applicable to the ore under examination. For confirmation of results, the cycle is repeated several times, usually with slight variations in an endeavour to arrive at near-optimum operating conditions.

Results were as follows:

Step (i) Digestion liquor at an $SO_3:Al_2O_3$ ratio of 2.61 was readily obtained from ore as received, with 90.7% extraction of alumina. Using ore calcined at 700° C prior to digestion, 95% extraction was obtained and less iron was dissolved than from uncalcined ore.

Step (ii) Modified digestion liquor at an $SO_3:Al_2O_3$ ratio of 1.91 was readily obtained, the ratio $Fe_2O_3:Al_2O_3$ being 0.09.

Step (iii) The residue from step (ii), which had lost approximately half of its available alumina, reacted with synthetic recycle liquor to give up further alumina into solution. The overall extraction of alumina in steps (ii) and (iii) was 83.2%. The digestion liquor produced was slightly more acid than expected, but this effect could be corrected by adding some fresh ore (as well as the modification residue) at the start of step (iii).

We thus regard the ore as being readily amenable to treatment by our acid process. Further work is being undertaken to reduce the amount of iron dissolved and to increase the percentage extraction of alumina, but these are relatively minor improvements. Problems which might arise from traces of undesirable impurities in the ore or from the filtration of settling stages have not been investigated.

The problems in utilizing southwest Washington laterite do not appear to be in the amount of material available for use, but rather are in the extractive metallurgy. The alumina content of the Oregon and Washington bauxite is low compared with ore that is utilized in the Bayer process. However, if a modification of the Pedersen process will give a high percent iron and aluminum recovery, or if the new leach processes are as economically feasible as reported, the Pacific Northwest bauxite deposits represent a substantial alumina reserve.

The fact that there are three alumina reduction plants—one each at Longview, Washington; Vancouver, Washington; and Troutdale, Oregon (just east of Portland)—in the general area of laterite occurrence, and that there are adequate power reserves for future expansion should make the ferruginous bauxite a most interesting commodity. Figure 21 shows the spatial relations of the Washington and Oregon deposits to each other and to the three cities that have reduction plants.

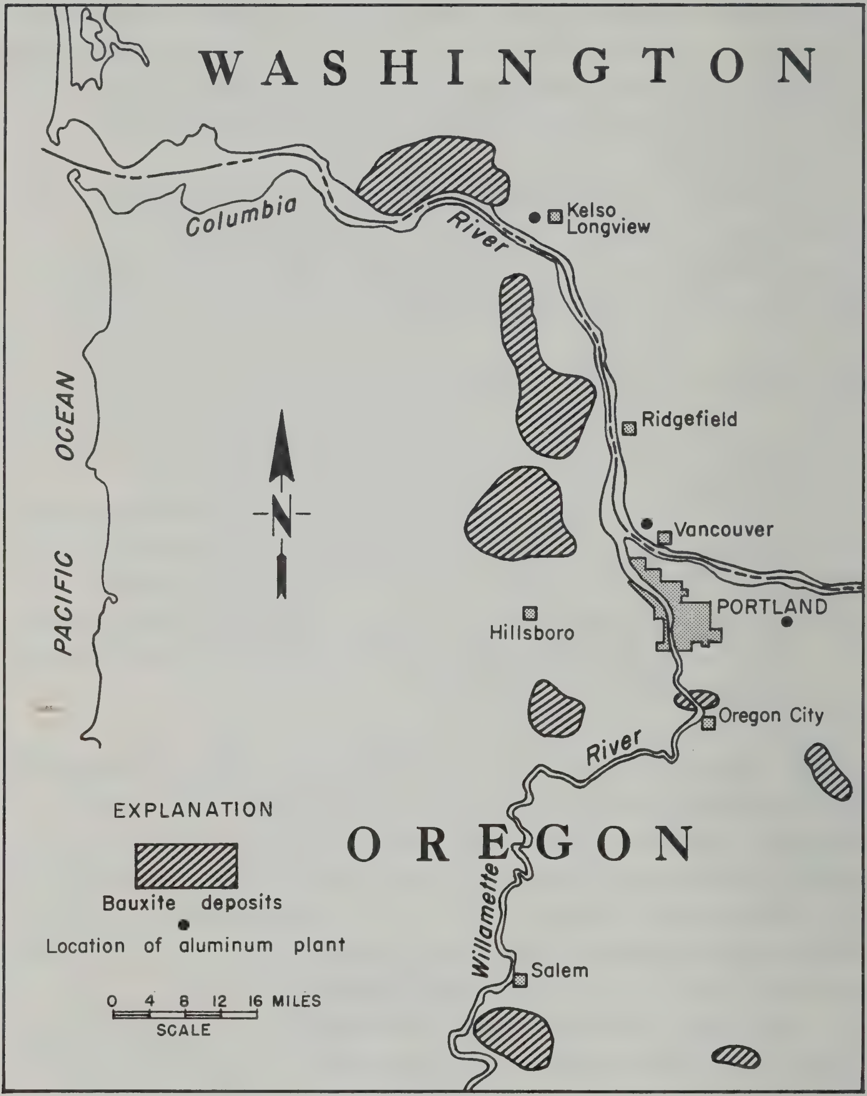

WASHINGTON
Columbia
River
Kelso
Longview
Ridgefield
Vancouver
PORTLAND
Hillsboro
Oregon City
River
PACIFIC OCEAN
N
EXPLANATION
Bauxite deposits
Location of aluminum plant
0 4 8 12 16 MILES
SCALE
OREGON
Willamette
Salem

FIGURE 21.—Spatial relations of the ferruginous bauxite deposits of Washington and Oregon.

## APPENDIX A—ANALYTICAL PROCEDURES

Given below are the analytical procedures used by two of the analysts in making the chemical analyses on the ferruginous bauxite.

### Northwest Testing Laboratories, Portland, Oregon

The sample was ground to a suitable degree of fineness, rolled and quartered, and then dried at 140° C to constant weight. A weighed sample was ignited in a covered crucible at 1,100° C to constant weight. Diminution in weight represented loss on ignition (L.O.I.). A suitable sample was fused with $Na_2CO_3$ in a platinum crucible. The melt was dissolved in dilute HCl. The HCl solution was dehydrated to dryness and baked at 105° C for 1 hour. The residue was dissolved in 1:1 HCl and the silica filtered. (This was repeated on several samples, with no appreciable $SiO_2$ picked up on the second dehydration). The silica was ignited at 1,100° C, cooled, weighed, fumed with 1:1 $H_2SO_4$ and HF, reignited, and weighed. The filtrate from the $SiO_2$ determination was diluted to 500 ml. A suitable aliquot was taken for FeO determination. Iron was reduced with $SnCl_2$ and determined volumetrically with Standard $KMnO_4$ (Zimmerman Reinhardt). An aliquot from the $SiO_2$ filtrate was taken, and the iron removed with $H_2S$. The solution then was transferred to a 100 ml volume and 10 ml of 1:1 $H_2SO_4$ and 3 ml of 3 percent $H_2O_2$ added. The yellow-orange color was read on an electrophotometer at 420 mu. The percent of $TiO_2$ then was calculated. A suitable aliquot of the silica filtrate was taken. The pH was adjusted to 11.0 with NaOH. Then the insoluble was filtered off and the filtrate containing the alumina saved. The pH of the filtrate was adjusted to 8.6 with HCl. The solution was heated to 90° C and alumina precipitated with a 5.0 percent solution of 8-hydroxyquinoline. The precipitate was washed, dried at 130° C to constant weight, and weighed. $Al\,(C_6H_6NO)_3$ contains 11.1 percent $Al_2O_3$.

### Metallurgical Laboratory, Seattle, Washington

Phosphate Method for Aluminum as Outlined by Keefer, of Anaconda

Fuse 0.5 g and remove first and second silica by evaporation and dehydration. To the filtrate add 10 g of ammonium chloride to insure solution of all aluminum as chloride. Add 30 ml of $NH_4OH$ and boil until only a faint odor of ammonia remains. Filter and wash well with hot water. Dissolve the precipitate with 1:1 HCl. To the clear solution add 50 ml of a 10 percent solution of $(NH_4)_2HPO_4$ and dilute to about 350 ml. Add ammonia until a slight permanent precipitate forms. Add 1.5 ml of HCl. The precipitate should entirely dissolve. Transfer to a liter beaker and add 35 ml of a 20 percent solution of sodium thiosulphate, and dilute to 750 ml. Heat to boiling and boil for one minute. Then add 25 ml of ammonium acetate mixture (made by dissolving 480 g of ammonium acetate in 1,650 ml of water and adding 750 ml of glacial acetic acid). Boil for 10 minutes. Remove from the heat and allow to settle for half an hour. Decant the clear liquid and filter the remainder, cleaning the beaker thoroughly. Wash at least ten times with hot water. If the salts are not entirely washed out, the resultant precipitate will fuse when it is burned. Cool and weigh as $AlPO_4$. This weight multiplied by 0.4185 is the weight of $Al_2O_3$.

### Caustic Soda Precipitation Method

To the solution after silica has been removed add a 10 percent solution of NaOH until nearly neutral. Heat to boiling, and while hot pour slowly with rapid stirring into 50 ml of a hot solution of 10 percent NaOH. Boil for a minute or two and allow to settle. Filter and wash thoroughly. Dissolve the precipitate and repeat the precipitation. To the combined filtrates add HCl until acid. Bring to a boil and add ammonia until faintly alkaline to litmus. Allow to settle and filter. Dissolve the precipitate in HCl and repeat the precipitation. Filter and wash thoroughly with hot water. Dry and ignite at 750° C. Cool and weigh as $Al_2O_3$.

### Cupferron Method

To the cold solution after removal of $SiO_2$ add an excess of a 10 percent water solution of Cupferron (nitrosophenylhydrosylamine) and stir rapidly for some time to insure coagulation of the precipitate and that the resultant solution is clear. After allowing to stand for 10 minutes, filter and wash thoroughly. If the iron precipitate is large, the precipitation should be repeated. The solution then is treated with 10 ml of $H_2SO_4$ and 10 ml of $HNO_3$ and evaporated to a very small bulk; more $HNO_3$ is added until all the carbon is oxidized. Bake off the $H_2SO_4$.

Cool and add 10 ml of HCl and 75 ml of water and bring to a boil. If the solution is not perfectly clear, filter. Add ammonia until faintly alkaline to litmus and boil for one minute. Allow to settle and filter and wash with hot water. Dissolve the precipitate with hot 1:1 HCl and repeat the precipitation. (If after dissolving with HCl the resultant solution is not perfectly clear, filter.) Filter and wash 10 times with hot water. Ignite and weigh as $Al_2O_3$.

## APPENDIX B—DESCRIPTION OF CORES

| Depth (feet) | Unit thickness (feet) | Lithologic description |
|---|---|---|
| Core hole No. 1, Henry Newt property<br>NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 6, T. 8 N., R. 3 W. | | |
| 0 - 4.5 | 4.5 | Brown silty soil becoming mottled with tan at base. |
| 4.5 - 13.5 | 9.0 | Rust-red silty clay mottled with black manganese stain at top, gray clay in lower part. Gray material imparts a wormy appearance or texture to the unit. Iron pisolites become abundant downward. |
| 13.5 - 37$\frac{1}{2}$ (bottom) | 24.0 | Mottled red, gray, and purple earthy clay that contains gibbsite-rich mustard-yellow to olive-brown nodules as much as 4 in. in diameter. Many of the nodules are vesicular. At about 24 ft manganese stain around nodules and in fractures begins to appear. As depth increases, manganese stain becomes heavier. |
| Core hole No. 2, J. R. Williamson property<br>NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 1, T. 8 N., R. 4 W. | | |
| 0 - 6.0 | 6.0 | Brown silty soil becoming mottled with a little gray near bottom. A few iron pisolites as much as $\frac{1}{2}$ in. in diameter occur near bottom. |
| 6.0 - 22.5 | 16.5 | Mottled rust-red, brown, and gray silty clay. Brown iron-rich pisolites are scattered abundantly through the unit. Quartz grains are visible through hand lens. Bottom 1.5 ft is totally rust-red in color. |
| 22.5 - 25.5 | 3.0 | Rust-red earthy clay. A few iron-rich pisolites are present. Pisolites are soft and earthy. |
| 25.5 - 43.5 | 18.0 | Mottled rust-red and brown earthy clay with olive-brown to mustard-yellow, hard, gibbsite-rich nodules as much as 4 in. in diameter. A few hard rindlike iron nodules are present. Some nodules are vesicular. |

Description of cores—Continued

| Depth (feet) | Unit thickness (feet) | Lithologic description |
|---|---|---|
| Core hole No. 2, J. R. Williamson property—Continued | | |
| 43.5 - 54.0 (bottom) | 10.5 | Mottled earthy clay, same as above. Banding has developed parallel to fractures in the original unaltered rock. Color is deep red along fractures. Nodules are present in the upper part only. Black manganese staining along fractures begins at about 48.0 ft. Clay in the bottom 6 ft is vesicular and looks like altered volcanic rock. Clay in the bottom part has hard breccia fragments that are soft and crumbly when wet. |
| Core hole No. 3, Longview Fibre Company property<br>NW¼NW¼ sec. 27, T. 9 N., R. 4 W. | | |
| 0 - 9.0 | 9.0 | Light-brown silt to clayey silt that contains a few dark-brown iron pisolites near the base. |
| 9.0 - 25½ | 16.5 | Mottled rust-red and gray silty clay. Contains abundant iron-rich pisolites. Mottling becomes indistinct at base of unit, and color becomes a more uniform rust-red. |
| 25.5 - 36 (bottom) | 10.5 | Pebble conglomerate, mottled red and brown with white. Pebbles and matrix are completely altered to clay. Black manganese staining is abundant near the bottom. |
| Core hole No. 4, Speer - Wagner property<br>SE¼SE¼ sec. 28, T. 9 N., R. 4 W. | | |
| 0 - 9.0 | 9.0 | Light-brown silt to clayey silt. No stratification is evident. Iron-rich pisolites are fairly common in the bottom 3 ft. |
| 9.0 - 33.0 | 24.0 | Mottled rust-red, brown, and gray clayey silt. No bedding is visible. Brown pisolites are abundant. A few gibbsite-rich nodules are present at the base of the unit. |
| 33.0 - 36.0 | 3.0 | Olive-gray to brown earthy clay with light-brown to yellow gibbsite-rich nodules. |

Description of cores—Continued

| Depth (feet) | Unit thickness (feet) | Lithologic description |
|---|---|---|
| Core hole No. 4, Speer - Wagner property—Continued | | |
| 36.0 - 51.0 (bottom) | 15.0 | Mottled red-brown and gray earthy clay. Parts of the unit have a fragmental appearance. Fractures are coated with black manganese stain. This is especially abundant at the bottom. |
| Core hole No. 5, J. H. Wallingford property<br>NW¼SE¼ sec. 2, T. 8 N., R. 5 W. | | |
| 0 - 9.0 | 9.0 | Light-brown silt to clayey silt. Quartz grains are easily seen. Small black manganese grains are present. A few brown iron pisolites are present at the base. |
| 9.0 - 28.5 | 19.5 | Mottled rust-red to brown silty clay that contains abundant brown iron-rich pisolites. Colors become darker downward. |
| 28.5 - 41.0 (bottom) | 12.5 | Olive-brown soft earthy clay that contains hard reddish vesicular fragments and small white clots of halloysite(?). Hard rindlike iron fragments are common in the unit. At 36.0 ft the color changes to mottled olive-brown, blue, and orange-red, and nodules are no longer present. There is fresh basalt at 41.0 ft. |
| Core hole No. 6, J. R. Williamson property<br>SW¼NW¼ sec. 31, T. 9 N., R. 3 W. | | |
| 0 - 3.0 | 3.0 | Light-brown silt to clayey silt. No stratification is evident. Quartz grains are abundant. A few brown iron-rich pisolites are present at the base. |
| 3.0 - 22.0 | 19.0 | Mottled rust-red, brown, and gray silty clay. No bedding is apparent. Brown iron-rich pisolites increase downward. Color is solid rust-red at the base. |

Description of cores—Continued

| Depth (feet) | Unit thickness (feet) | Lithologic description |
|---|---|---|
| Core hole No. 6, J. R. Williamson property—Continued | | |
| 22.0 - 39.0 | 17.0 | Mottled rust-red and olive-brown earthy clay. The top 3 ft has light-brown pisolites. Below this, mustard-yellow gibbsite nodules occur in the clay. Nodules are often vesicular. Manganese staining along fractures is present near the bottom. |
| 39.0 - 45.0 (bottom) | 6.0 | Red to reddish-brown altered vesicular basalt. The material is very brittle and crumbles easily. Fractures are heavily coated with black manganese oxide. |
| Core hole No. 7, A. D. Baker property<br>SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 25, T. 9 N., R. 4 W. | | |
| 0 - 9.0 | 9.0 | Light-brown silt to clayey silt. Has small soft black manganese oxide clots sparsely scattered through the unit. |
| 9.0 - 32.0 | 23.0 | Reddish-brown silty clay becoming mottled at about 15 ft. Brown iron-rich pisolites are scattered through the unit. Some olive-brown gibbsite nodules are present at the base of the unit. |
| 32.0 - 45 (bottom) | 13.0 | Olive-brown earthy clay; the bottom part has a more reddish hue. Lower part of the unit is vesicular; has the appearance of altered basalt. Black manganese stain along fractures becomes increasingly heavy downward. |
| Core hole No. 8, Jess Byrum property<br>SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 34, T. 9 N., R. 3 W. | | |
| 0 - 6.5 | 6.5 | Light-brown silt to silty clay. |
| 6.5 - 28.5 | 22.0 | Rust-red to light-brown mottled silty clay. A few brown iron-rich pisolites are present. Near the bottom, rindlike iron nodules occur. |
| 28.5 - 33.0 (bottom) | 4.5 | Round pebble conglomerate in a sandy matrix. Pebbles and matrix have been completely altered to clay. |

Description of cores—Continued

| Depth (feet) | Unit thickness (feet) | Lithologic description |
|---|---|---|
| Core hole No. 9, State of Washington property<br>SE¼SE¼ sec. 1, T. 8 N., R. 5 W. | | |
| 0 - 4.5 | 4.5 | Light-brown clayey silt. Has a few small rust-red iron concretions at the base. |
| 4.5 - 25.0 | 20.5 | Mottled rust-red and light-brown silty clay. Contains brown iron-rich pisolites that are most abundant at the base. Quartz grains are abundant. |
| 25.0 - 39.0 (bottom) | 14.0 | Mottled olive-brown and red altered basalt-textured clay. Parts are vesicular. Black manganese stain is heavy at the base. |
| Core hole No. 10, Longview Fibre Company property<br>SW¼SW¼ sec. 22, T. 9 N., R. 4 W. | | |
| 0 - 12.0 | 12.0 | Light-brown silt to clayey silt. Quartz and mica are easily visible with a hand lens. No stratification is apparent. |
| 12.0 - 28.0 | 16.0 | Mottled rust-red and light-brown silty clay, banded in places. Brown iron-rich pisolites are present through the unit but are not abundant. |
| 28.0 - 51.0 | 23.0 | Pebble conglomerate in a sandy matrix. Everything is altered to clay. |
| 51.0 - 67.5 (bottom) | 16.5 | Mottled and banded buff to gray sandstone. Completely altered at the top, less so at the bottom. |

## SELECTED REFERENCES

Allen, V. T., 1948, Formation of bauxite from basaltic rocks in Oregon: Econ. Geology, v. 43, no. 8, p. 619-626.

Allison, I. S., 1932a, New version of the Spokane flood: Geol. Soc. America Bull., v. 44, p. 675-722.

Allison, I. S., 1932b, Spokane flood south of Portland, Oregon [abs.]: Geol. Soc. America Bull., v. 43, p. 133-134.

Arnold, Ralph, 1906, Geological reconnaissance of the coast of the Olympic Peninsula, Washington: Geol. Soc. America Bull., v. 17, p. 451-468.

Arnold, Ralph, 1909, Environment of the Tertiary faunas of the Pacific Coast of the United States: Jour. Geology, v. 17, p. 509-533.

Arnold, Ralph, and Hannibal, Harold, 1913, The marine Tertiary stratigraphy of the north Pacific Coast of America: Am. Philos. Soc. Proc., v. 52, p. 559-605.

Beck, R. S., 1943, Eocene Foraminifera from Cowlitz River, Lewis County, Washington: Jour. Paleontology, v. 17, no. 6, p. 584-614.

Beikman, H. M., Gower, H. D., and Dana, T. A. M., 1961, Coal reserves of Washington: Washington Div. Mines and Geology Bull. 47, 115 p.

Bennett, W. A. G., 1939, Bibliography and index of geology and mineral resources of Washington, 1814-1936: Washington Div. Geology Bull. 35, 140 p.

Bretz, J H., 1913, Glaciation of the Puget Sound region: Washington Geol. Survey Bull. 8, 244 p.

Campbell, C. D., 1953, Introduction to Washington geology and resources: Washington Div. Mines and Geology Inf. Circ. 22R, 44 p.

Chaney, R. W., 1944, Pliocene floras of California and Oregon, chap. 11, The Dalles flora, chap. 12, The Troutdale flora: Carnegie Inst. Washington, Pub. 553, p. 323-352.

Chittenden, J. S., and Moulton, R. W., 1951, Preliminary study of the recovery of alumina from the Oregon laterites: The Trend in Engineering at the University of Washington, v. 3, no. 1, p. 18-22 (Condensed by N. R. Mukherjee from M.S. thesis by J. S. Chittenden, Univ. of Washington, 1948).

Corcoran, R. E., 1962, Bauxite deposits of the Salem Hills, Marion County, Oregon: Geol. Soc. Oregon Country Geol. News-Letter, v. 28, no. 5, p. 25-28.

Corcoran, R. E., and Libbey, F. W., 1956, Ferruginous bauxite deposits in the Salem Hills, Marion County, Oregon: Oregon Dept. Geol. and Mineral Industries Bull. 46, 53 p.

Culver, H. E., 1919, The coal fields of southwestern Washington: Washington Geol. Survey Bull. 19, 155 p.

Culver, H. E., 1936, The geology of Washington; General features of Washington geology (with preliminary geologic map in colors): Washington Div. Geol. Bull. 32, 70 p.

Cushman, J. A., Stewart, R. E., and Stewart, K. C., 1949, Upper Eocene Foraminifera from the Toledo Formation, Toledo, Lincoln County, Oregon: Oregon Dept. Geol. and Mineral Industries Bull. 36, pt. 4, p. 113-144.

Dana, J. D., 1849, Notes on the geology of Washington Territory. In Geology: United States exploring expedition during the years 1838, 1839, 1840, 1841, 1842, under the command of Charles Wilkes, USN, v. 10, p. 616-621, 626-628, 658.

Darton, N. H., 1909, Structural materials in parts of Oregon and Washington: U.S. Geol. Survey Bull. 387, 33 p.

de Sitter, L. U., 1956, Structural geology: McGraw-Hill, New York, 552 p.

Dickerson, R. E., 1915, Fauna of the type Tejon; its relation to the Cowlitz phase of the Tejon Group of Washington: California Acad. Sci. Proc., 4th ser., v. 5, p. 33-98.

Diller, J. S., 1896, A geological reconnaissance in northwestern Oregon: U.S. Geol. Survey 17th Ann. Rept., pt. 1, p. 441-520.

Diller, J. S., 1905, Coal in Washington near Portland, Oregon. In Contributions to Economic Geology, 1904: U.S. Geol. Survey Bull. 260, p. 411-412.

Diller, J. S., and others, 1916, Guidebook of the western United States; Part D.— The Shasta Route and coast line: U.S. Geol. Survey Bull. 614, p. 23-24.

Durham, J. W., 1950, Cenozoic marine climates of the Pacific Coast: Geol. Soc. America Bull., v. 61, no. 11, p. 1243-1264.

Frondel, Clifford, 1962, The system of mineralogy; Volume 3.— Silica minerals, 7th ed.: John Wiley and Sons, Inc., New York and London, 334 p.

Glover, S. L., 1941, Clays and shales of Washington: Washington Div. Geology Bull. 24, 368 p.

Grubb, P. L. C., 1963, Critical factors in the genesis, extent, and grade of some residual bauxite deposits: Econ. Geology, v. 58, p. 1267-1277.

Hanna, G. D., and Hanna, M. H., 1924, Foraminifera from the Eocene of Cowlitz River, Lewis County, Washington: Univ. of Washington Pub. in Geology, v. 1, no. 4, p. 57-64.

Henriksen, D. A., 1956, Eocene stratigraphy of the lower Cowlitz River-eastern Willapa Hills area, southwestern Washington: Washington Div. Mines and Geology Bull. 43, 122 p.

Hertlein, L. G., and Crickmay, C. H., 1925, A summary of the nomenclature and stratigraphy of the marine Tertiary of Oregon and Washington: Am. Philos. Soc. Proc., v. 64, p. 224-282.

Hodge, E. T., 1933, Age of Columbia River and lower canyon [abs.]: Geol. Soc. America Bull., v. 44, pt. 1, p. 156-157.

Hodge, E. T., 1938, Geology of the lower Columbia River: Geol. Soc. America Bull., v. 49, p. 831-929.

Holbrook, W. F., and Yerkes, L. A., 1963, Extraction of alumina from ferruginous bauxite by a double-leach process: U.S. Bur. Mines Rept. Inv. 6280, 20 p.

Huntting, M. T., Bennett, W. A. G., Livingston, V. E., Jr., and Moen, W. S., 1961, Geologic map of Washington: Washington Div. Mines and Geology, scale, 1:500,000.

Kelly, J. V., 1947, High alumina-iron laterite deposits, Columbia County, Oregon: U.S. Bur. Mines Rept. Inv. 4081, 51 p.

Landes, Henry, 1902, The coal deposits of Washington: Washington Geol. Survey Ann. Rept. 1901, pt. 4, p. 41-65.

Landes, Henry, and Ruddy, C. A., 1903, Coal deposits of Washington: Washington Geol. Survey Ann. Rept. 1902, pt. 2, p. 167-277.

Libbey, F. W., Lowry, W. D., and Mason, R. S., 1945, Ferruginous bauxite deposits in northwestern Oregon: Oregon Dept. Geol. and Mineral Industries Bull. 29, 97 p.

Libbey, F. W., Lowry, W. D., and Mason, R. S., 1946, Ferruginous bauxite deposits in northwestern Oregon: Econ. Geology, v. 41, no. 3, p. 246-265.

Lowry, W. D., and Baldwin, E. M., 1952, Late Cenozoic geology of the lower Columbia River valley, Oregon and Washington: Geol. Soc. America Bull., v. 63, no. 1, p. 1-24.

McCarthy, C. E., Cole, R. S., Nichols, E. F., Wilson, Hewitt, and Ruppert, J. A., 1949, Recovery of alumina from submarginal bauxites; Part 1.—Electric furnace production of calcium aluminate and ferro-alloy: U.S. Bur. Mines Rept. Inv. 4527, 93 p.

Pease, M. H., Jr., and Hoover, Linn, Jr., 1957, Geology of the Doty-Minot Peak area, Washington: U.S. Geol. Survey Oil and Gas Inv. Map OM-188.

Peck, D. L., 1961, Geologic map of Oregon west of the 121st meridian: Oregon Dept. Geol. and Mineral Industries.

Rau, W. W., 1958, Stratigraphy and foraminiferal zonation in some of the Tertiary rocks of southwestern Washington: U.S. Geol. Survey Chart OC-57.

Reichert, W. H., 1960, Bibliography and index of the geology and mineral resources of Washington, 1937-1956: Washington Div. Mines and Geology Bull. 46, 721 p.

Roberts, A. E., 1958, Geology and coal resources of the Toledo-Castle Rock district, Cowlitz and Lewis Counties, Washington: U.S. Geol. Survey Bull. 1062, 71 p.

Russell, I. C., 1893, A geological reconnaissance in central Washington: U.S. Geol. Survey Bull. 108, 108 p.

Scott. T. R., 1962, Alumina by acid extraction: Jour. Metals, v. 14, no. 2, p. 121-125.

Snavely, P. D., Jr., Roberts, A. E., Hoover, Linn, Jr., and Pease, M. H., Jr., 1951, Geology of the eastern part of the Centralia-Chehalis coal district, Lewis and Thurston Counties, Washington: U.S. Geol. Survey Coal Inv. Map C-8.

Snavely, P. D., Jr., Rau, W. W., Hoover, Linn, Jr., and Roberts, A. E., 1951, McIntosh Formation, Centralia-Chehalis coal district, Washington: Am. Assoc. Petroleum Geologists Bull., v. 35, no. 5, p. 1052-1061.

Snavely, P. D., Jr., Brown, R. D., Jr., Roberts, A. E., Rau, W. W., Hoover, Linn, Jr., and Pease, M. H., Jr., 1954, Geology and coal resources of the Centralia-Chehalis coal district, Lewis and Thurston Counties, Washington [abs.]: Sci., v. 119, no. 3091, p. 419-420.

Snavely, P. D., Jr., Brown, R. D., Jr., Roberts, A. E., and Rau, W. W., 1958, Geology and coal resources of the Centralia-Chehalis district, Washington: U.S. Geol. Survey Bull. 1053, 159 p.

Snavely, P. D., Jr., and Wagner, H. C., 1963, Tertiary geologic history of western Oregon and Washington: Washington Div. Mines and Geology Rept. Inv. 22, 25 p.

Thompson, M. R., McLeod, H. M., Jr., and Skow, M. L., 1949, Recovery of alumina from submarginal bauxites; Part 2.—Extraction of alumina from electric-furnace slags of calcium aluminate: U.S. Bur. Mines Rept. Inv. 4528, 91 p.

Treasher, R. C., 1938, A Pleistocene damming of the lower Columbia River [abs.]: Geol. Soc. Oregon Country Geol. News-Letter, v. 4, no. 24, p. 271.

Treasher, R. C., 1942, Geologic history of the Portland area: Oregon Dept. Geol. and Mineral Industries Short Paper 7, 17 p.

Trimble, D. E., 1957, Geology of the Portland quadrangle, Oregon-Washington: U.S. Geol. Survey Geol. Quad. Maps of the United States, Map GQ-104.

Trimble, D. E.,1963, Geology of Portland, Oregon, and adjacent areas: U.S. Geol. Survey Bull. 1119, 119 p.

U.S. Board on Geographic Names, 1959, Decisions of names in the United States, Puerto Rico, and the Virgin Islands: U.S. Board on Geographic Names Decision List 5901, 100 p.

Warren, W. C., Norbisrath, Hans, and Grivetti, R. M., 1945, Geology of northwest Oregon west of Willamette River and north of latitude 45°15': U.S. Geol. Survey Oil and Gas Inv. (Prelim.) Map 42.

Washburne, C. W., 1914, Reconnaissance of the geology and oil prospects of northwestern Oregon: U.S. Geol. Survey Bull. 590, 111 p.

Washington Div. Water Resources, 1955, Monthly and yearly summaries of hydrographic data in the State of Washington to September, 1953: Washington Div. Water Resources Water Supply Bull. 6, 836 p.

Weaver, C. E., 1912, A preliminary report on the Tertiary paleontology of western Washington: Washington Geol. Survey Bull. 15, 80 p.

Weaver, C. E., 1916a, The Tertiary formations of western Washington: Washington Geol. Survey Bull. 13, 327 p.

Weaver, C. E., 1916b, Eocene of the lower Cowlitz River valley, Washington: California Acad. Sci. Proc., 4th ser., v. 6, p. 1-17.

Weaver, C. E., 1916c, Tertiary faunal horizons of western Washington: Univ. of Washington Pub. in Geology, v. 1, p. 1-67.

Weaver, C. E., 1930, Eocene lavas in western Washington [abs.]: Geol. Soc. America Bull., v. 41, p. 87.

Weaver, C. E., 1933, Western Washington's formations compared with California's: Northwest Oil and Gas World, v. 3, no. 4, p. 1, 3; v. 3, no. 5, p. 1, 3.

Weaver, C. E., 1937a, Stratigraphy of the type section of the Cowlitz Formation along Olequah Creek, Washington [abs.]: Geol. Soc. America Proc. 1936, p. 298.

Weaver, C. E., 1937b, Tertiary stratigraphy of western Washington and northwestern Oregon: Univ. of Washington Pub. in Geology, v. 4, 266 p.

Weaver, C. E., 1939, Metchosin volcanic rocks in Oregon and Washington [abs.]: Geol. Soc. America Bull., v. 50, p. 1961.

Weaver, C. E., 1943, Paleontology of the marine Tertiary formations of Oregon and Washington: Univ. of Washington Pub. in Geology, v. 5, 789 p., printed in 1942, issued 1943.

Weaver, C. E., 1945, Geology of Oregon and Washington and its relation to occurrence of oil and gas: Am. Assoc. Petroleum Geologists Bull., v. 29, no. 10, p. 1377-1415.

Weaver, C. E., and Palmer, K. V. W., 1922, Fauna from the Eocene of Washington: Univ. of Washington Pub. in Geology, v. 1, no. 3, p. 1-56.

Weaver, C. E., and others, 1944, Correlation of the marine Cenozoic formations of western North America: Geol. Soc. America Bull., v. 55, p. 569-598.

Wilkinson, W. D., Lowry, W. D., and Baldwin, E. M., 1946, Geology of the St. Helens quadrangle, Oregon: Oregon Dept. Geol. and Mineral Industries Bull. 31, 39 p.

Willis, Bailey, 1880, Report on the coal fields of Washington Territory: Tenth Census of the U.S., v. 15, p. 759-771.

557
W27b
no. 54

## EXPLANATION

### SEDIMENTARY AND
### TRUSIVE IGNEOUS ROCKS

Qa

**Alluvium**

ravel, silt, and peat deposts along stream courses

Qls

**Landslide**

of detached and slumped bedrock and overburden

Qt

**Terrace deposits**

Silt and fine sand along valley walls

▨

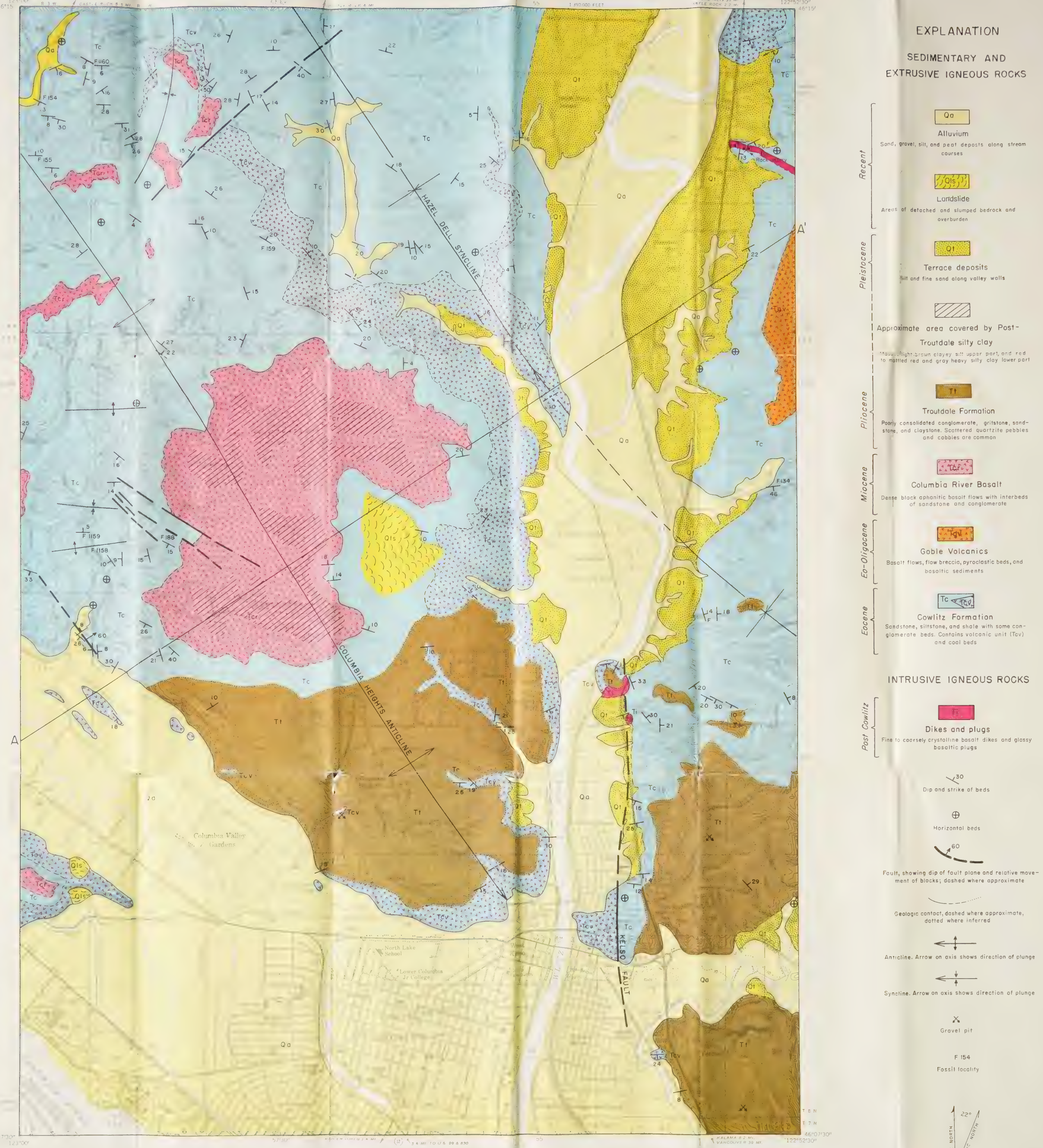
**imate area covered by Post-Troutdale silty clay**

ight brown clayey silt upper part and red

W-27
no. 5

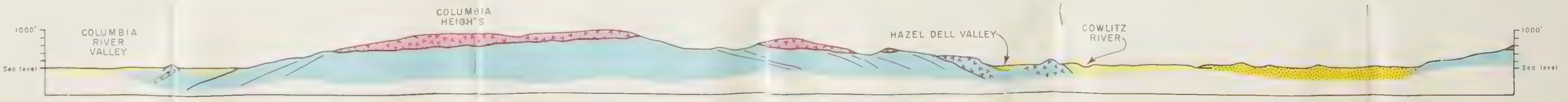
DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

BULLETIN 54
FIGURE 22


46°15'
123°00'
R 3 W
CASTLE ROCK 5.3 MI.
1 390 000 FEET
CHEHALIS 36 MI.
CASTLE ROCK 2.2 MI.
122°52'30"
46°15'
HAZEL DELL SYNCLINE
COLUMBIA HEIGHTS ANTICLINE
KELSO FAULT
A
A'
Rock Quarry
Columbia Valley Gardens
North Lake School
Lower Columbia Jr College
Qa
Qls
Qt
Tt
Tcr
Tgv
Tc
Tcv
Ti
F 160
F 154
F 155
F 159
F 188
F 158
F 134
T 8 N
T 7 N
46°07'30"
123°00'
57'30"
55
KALAMA 8.2 MI.
VANCOUVER 39 MI.
122°52'30"
46°07'30"
EXPLANATION
SEDIMENTARY AND EXTRUSIVE IGNEOUS ROCKS
Recent
Qa
Alluvium
Sand, gravel, silt, and peat deposits along stream courses
Qls
Landslide
Areas of detached and slumped bedrock and overburden
Pleistocene
Qt
Terrace deposits
Silt and fine sand along valley walls
Approximate area covered by Post-Troutdale silty clay
Yellowish light-brown clayey silt upper part, and red to mottled red and gray heavy silty clay lower part
Pliocene
Tt
Troutdale Formation
Poorly consolidated conglomerate, gritstone, sandstone, and claystone. Scattered quartzite pebbles and cobbles are common
Miocene
Tcr
Columbia River Basalt
Dense black aphanitic basalt flows with interbeds of sandstone and conglomerate
Eo-Oligocene
Tgv
Goble Volcanics
Basalt flows, flow breccia, pyroclastic beds, and basaltic sediments
Eocene
Tc
Tcv
Cowlitz Formation
Sandstone, siltstone, and shale with some conglomerate beds. Contains volcanic unit (Tcv) and coal beds
INTRUSIVE IGNEOUS ROCKS
Post Cowlitz
Ti
Dikes and plugs
Fine to coarsely crystalline basalt dikes and glassy basaltic plugs
30
Dip and strike of beds
Horizontal beds
60
Fault, showing dip of fault plane and relative movement of blocks; dashed where approximate
Geologic contact, dashed where approximate, dotted where inferred
Anticline. Arrow on axis shows direction of plunge
Syncline. Arrow on axis shows direction of plunge
Gravel pit
F 154
Fossil locality
22°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1953

Base from U.S. Geological Survey Kelso Quadrangle

Geology by Vaughn E. Livingston, Jr., 1959


1000'
Sea level
COLUMBIA RIVER VALLEY
COLUMBIA HEIGHTS
HAZEL DELL VALLEY
COWLITZ RIVER
1000'
Sea level

Cross section A — A'

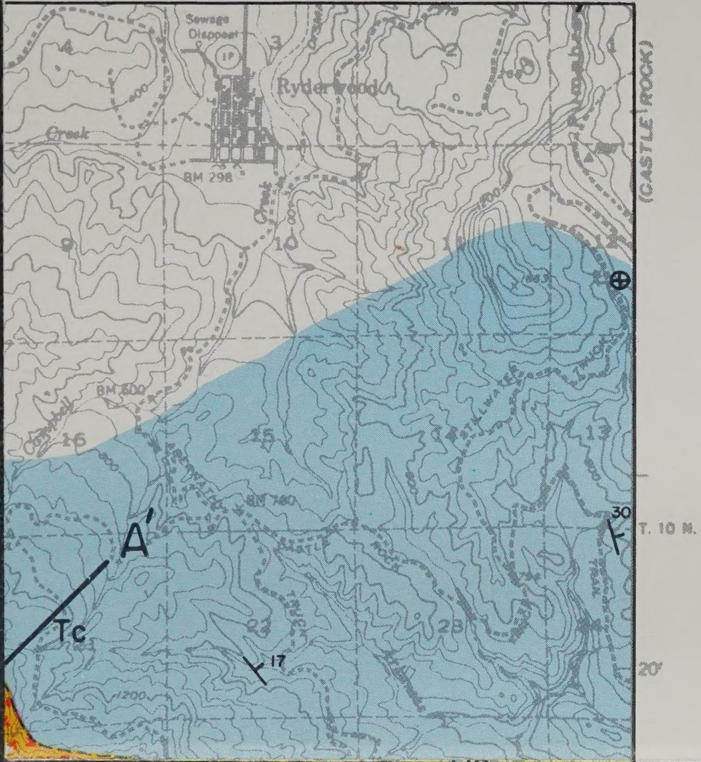
## GEOLOGIC MAP AND CROSS SECTION OF THE KELSO 7 1/2-MINUTE QUADRANGLE

SCALE 1:24,000

0 1/2 1 2 Miles

557
W27b
no. 54

BULLETIN 54
FIGURE 23


Sewage Disposal
Ryderwood
Creek
BM 298
BM 800
BM 780
A'
Tc
30
17
15
16
13
23
28
(CASTLE ROCK)
T. 10 N.
20'

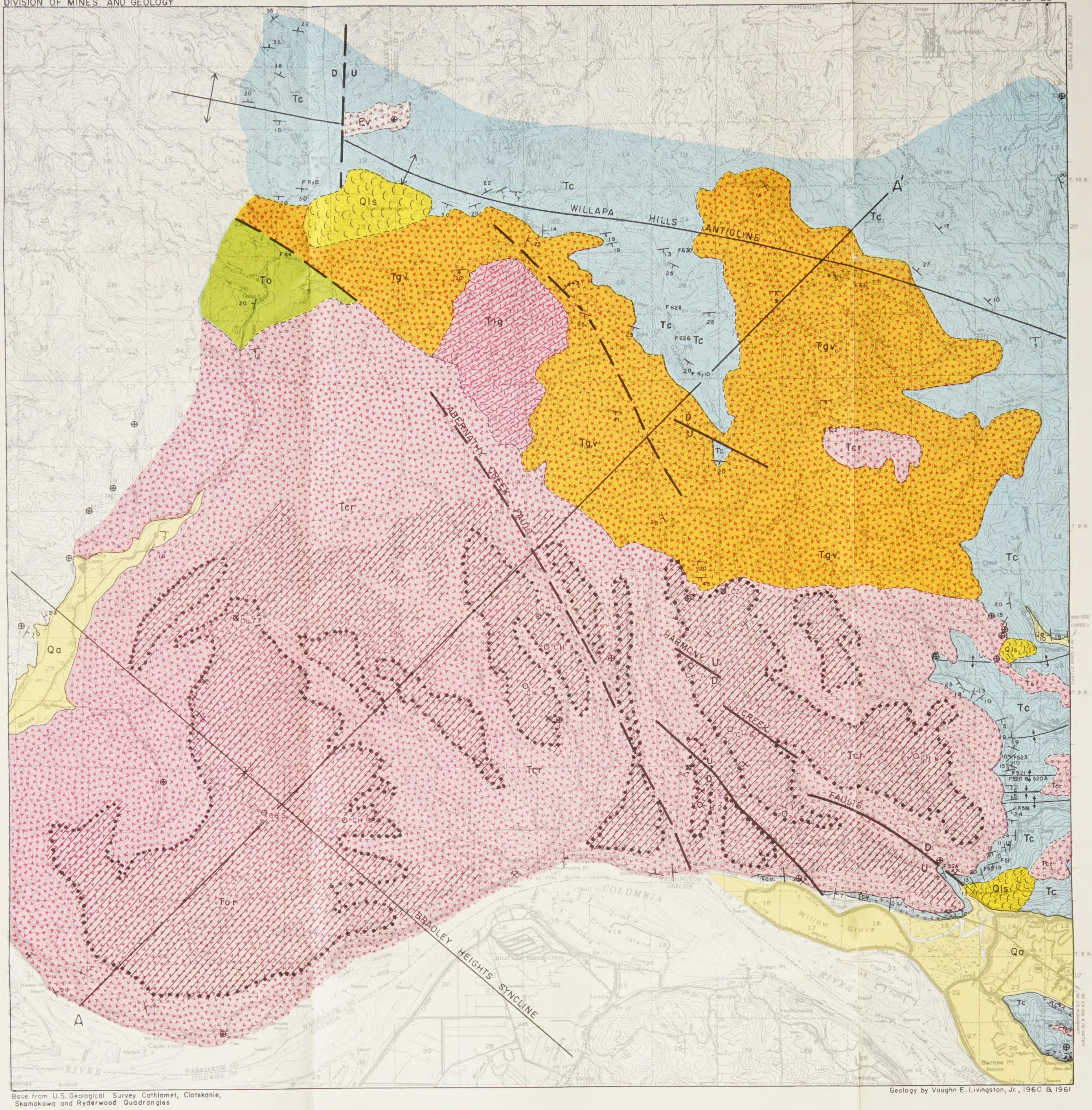
## EXPLANATION

### SEDIMENTARY AND
### EXTRUSIVE IGNEOUS ROCKS

W276
no. 54

DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

BULLETIN 54
FIGURE 23


D
U
Ev
Tc
Qls
To
Tgv
Tig
Tcr
Tcv
Qa
WILLAPA HILLS ANTICLINE
ABERNATHY CREEK FAULT
HARMONY
CREEK FAULT
BRADLEY HEIGHTS SYNCLINE
COLUMBIA
RIVER
Willow Grove
A
A'
Ca 77
CH 7
F 626
F 628
F 630
Barlow Pt
Cape Horn

Base from U.S. Geological Survey Cathlamet, Clatskanie, Skamokawa and Ryderwood Quadrangles

Geology by Vaughn E. Livingston, Jr., 1960 & 1961

## EXPLANATION

### SEDIMENTARY AND EXTRUSIVE IGNEOUS ROCKS

*Recent*

**Qa**

Alluvium

Sand, gravel, silt, and peat along streams

**Qls**

Landslide

Areas of detached and slumped bedrock and overburden

*Plio-Pleistocene*

▨

Post-Troutdale silty clay

Massive light-brown clayey silt upper part, and red to mottled red and gray heavy silty clay lower part. At most places has a gibbsite-rich pisolitic zone at base

*Miocene*

**Tcr**

Columbia River Basalt

Dense black aphanitic basalt flows with interbeds of sandstone and conglomerate

*Oligocene*

**To**

Oligocene sedimentary rocks

Massive dark to light-gray siltstone

*Eo-Oligocene*

**Tgv**

Goble Volcanics

Basalt flows, flow breccia, pyroclastic beds, and basaltic sediments

*Eocene*

**Tc** **Tcv**

Cowlitz Formation

Sandstone, siltstone, and shale with some conglomerate beds. Contains volcanic unit (Tcv) and coal beds

**Ev**

Older Eocene volcanics

Light-gray, soft, altered basalt flows

### INTRUSIVE IGNEOUS ROCKS

*Post-Cowlitz*

**Tig**

Hypabyssal intrusive

20

Dip and strike of beds

U D 45

Fault, dashed where approximate, showing dip of fault plane and relative movement of blocks

Geologic contact, dashed where indefinite

Areas within which the geology and topography appear to be favorable for the occurrence of ferruginous bauxite

Syncline

Anticline

⚒

Rock quarry

○ CH 7

Core hole

⊠ Ca 77

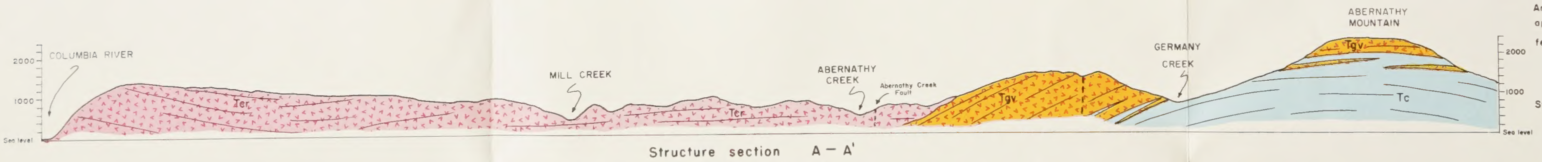
Channel sample

×

Bauxite nodule occurrence

F 57

Fossil locality

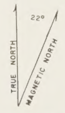

2000
1000
Sea level
COLUMBIA RIVER
MILL CREEK
ABERNATHY CREEK
Abernathy Creek Fault
GERMANY CREEK
ABERNATHY MOUNTAIN
Tcr
Tgv
Tc

Structure section A — A'

(Vertical exaggeration x2.5)

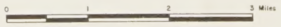
# PRELIMINARY GEOLOGIC MAP AND CROSS SECTION OF THE CATHLAMET - COAL CREEK AREA

## COWLITZ AND WAHKIAKUM COUNTIES, WASHINGTON


22°
TRUE NORTH
MAGNETIC NORTH

APPROXIMATE MEAN DECLINATION, 1953

SCALE
1:62,500



UNIVERSITY OF ILLINOIS-URBANA
557W27B C001
BULLETIN OLYMPIA
54 1966
3 0112 026934668